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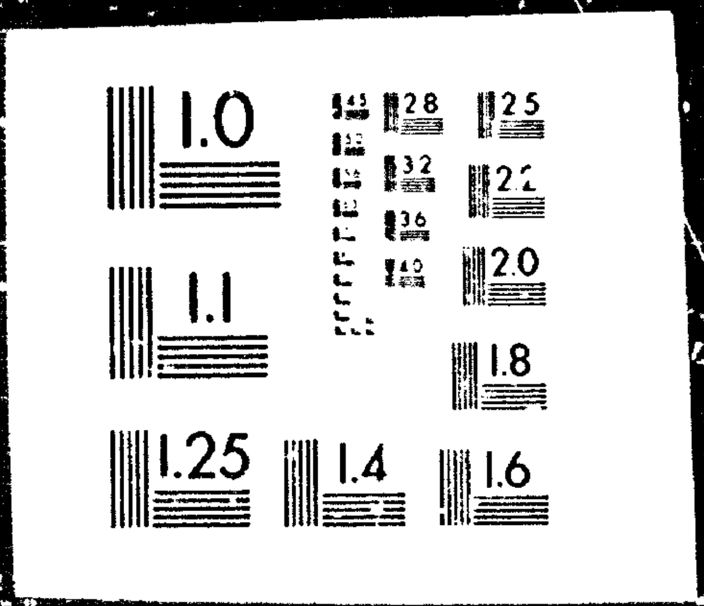

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Safety Effectiveness Evaluation Selected State Highway Skid Resistance Programs

(U.S.) National Transportation Safety Board
Washington, DC

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NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SAFETY EFFECTIVENESS EVALUATION SELECTED STATE HIGHWAY SKID RESISTANCE PROGRAMS

NTSB-SEE-80-6

UNITED STATES GOVERNMENT

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16. Abstract

The National Transportation Safety Board has investigated 12 highway accidents involving wet pavement, reviewed the skid resistance programs of 10 States, reviewed the States' responses to the Federal Highway Administration's (FHWA) Advance Notice of Proposed Rulemaking, "Skid Accident Reduction Program - FHWA Docket No. 77-16," conducted a special study on the magnitude of the wet pavement problem, and conducted a limited review of literature reporting research activity conducted by the States.

There is a lack of systematic application of proven principles and practices by the States and FHWA. Past FHWA approaches have not been successful. As examples, the Board found that some of the fundamental skid resistance principles that are accepted today have been known over 20 years, that many local or county roads have never been skid tested, and that more than one State does not use accident records to define where testing is needed.

As a result of this evaluation, the Board recommends that FHWA develop program objectives, initiate rulemaking to require that each State have an approved program with specific elements, revise the Federal-aid Highway Program Manual (FHPM 6.2.4.3), promote further research in several areas, and disseminate information more effectively.

17. Key Words Skid resistance, locked wheel skid trailers, accidents on wet pavements, skid numbers, smooth tire testing, skid trailer calibration, aggregate testing, texture, State skid resistance programs		18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
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FOREWORD

The mission of the National Transportation Safety Board is to improve transportation safety. This is done by determining the probable cause of accidents through on-scene investigations, public hearings, and staff review and analysis of accident information; by evaluations of operations, effectiveness, and performance of other agencies; by special studies and safety investigations; and by published recommendations and reports.

Since its establishment, the Safety Board has been concerned that solutions to certain safety problems of national significance have not been implemented as rapidly as possible, even though the solutions were known, feasible, and timely. Therefore, the Safety Board has begun to select several problems for emphasis each year through a safety objectives program and to aggressively pursue the implementation of specific safety improvements. One of these safety objectives during fiscal years 1979 and 1980 was to encourage States to resurface highways and roads with surface mixes that provide good skid resistance. As the work progressed, the scope of the project was expanded to a systems analysis of the many aspects of a skid resistance program. Emphasis was placed on "new" pavement surfaces because, when pavements are being constructed or reconstructed, the cost of providing a good skid resistant surface is least. The Board realizes that it is not economically feasible to improve all existing roadways immediately, but if good skid resistant surfaces were provided initially which maintain an acceptable frictional level throughout their life, over the years, the frictional characteristics of the highway system would improve.

States continually reiterate the need for self-determination in establishing guidelines for their programs. Often in the past, programs have been established that do not provide the States with the flexibility needed to account for the economic and natural resource constraints that existed within the State. Sometimes States are hesitant to adopt or implement programs, because they did not have the opportunity to contribute to the design of the program. The Safety Board has noted these preferences and has tried to develop a model skid resistance program that will provide flexibility and will offer a greater possibility for success.

Based on field experience, many States have opposed a standard specifying a minimum skid number that all road surfaces would have to meet. Arguments against establishing a minimum skid number center around its unreliability because of seasonal variations, the economic burden that would be placed on some States to upgrade all roads, and the use of scarce funds to upgrade roads that do not have a history of skidding accidents. Inspite of these arguments, minimal guidelines need to be established to define State responsibility for providing a safe roadway environment.

To that end, the Safety Board initiated a three-phase program to highlight problem areas and to develop countermeasures. The three phases were--

1. A special study of fatal accidents and weather statistics to develop a methodology to determine the magnitude and location of the problem.

2. Accident investigations and review of previous Safety Board investigations to identify factors that contribute to wet weather accidents.

3. Evaluation of the skid resistance programs of 10 selected States to determine existing operational problems and to gain insights that would permit the formulation of a more systematic and comprehensive skid resistance program to reduce the number of wet weather accidents nationwide.

The special study (1) has been conducted and its results released to the public. Phases two and three are reported on in this Safety Effectiveness Evaluation.

State skid resistance programs were selected for review in cooperation with the Federal Highway Administration (FHWA). The States were representative of most of the FHWA regions. After all the selected States were reviewed, their skid resistance programs were subjectively ranked by the Safety Board's staff from best to worst. Those programs that were judged subjectively to be more progressive used accident records for determining locations to be tested, had specified minimum skid numbers or ranges which triggered improvement of the locations, rated aggregates and quarries, and had many other elements in their programs. States that used these approaches were not among the 25 States with high indexes, 1/ as established in the Safety Board's special study (1).

Throughout this report, when referring to the number of States with certain practices, qualitative adjectives, such as most, many, some, few, or a couple are used because some States' practices vary only slightly from others, not all States were asked every question, and some questions were subjective rather than quantitative. This evaluation is not intended to be a concensus of State viewpoints, but rather a comparison of practices looking to the development of an effective, comprehensive program. No attempts were made to verify all the opinions expressed by the States since this was beyond the scope of this study.

The Safety Board does not believe that all or even a significant portion of wet-pavement accidents are solely the result of inferior pavements. On the other hand, the Board believes that inferior pavements with above-average accident experience are relatively easy to identify and should be a promising area for the reduction of wet-pavement accidents.

1/ The index was the ratio of the percentage of fatal accidents on wet pavement divided by the percentage of wet time. Those States with high indexes have a higher rate than the average which indicates that more fatal accidents tended to occur on wet pavement than would normally be expected.

The Safety Board sincerely appreciates the cooperation and contributions of those individuals, States, Federal agencies, and organizations who contributed to this Safety Effectiveness Evaluation. Those involved in the program reviews included the Federal Highway Administration (FHWA), the State transportation/highway departments of California, Florida, Mississippi, Missouri, Nebraska, New York, Pennsylvania, Texas, Virginia, and Washington. Other States that provided assistance in this project were Alabama, Connecticut, Illinois, Indiana, Kansas, Michigan, North Carolina, Oregon, Utah, Vermont, and individuals on the staff of the Texas Transportation Institute (T.T.I.).

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

SAFETY EFFECTIVENESS EVALUATION

Adopted: September 29, 1980

SELECTED STATE HIGHWAY SKID RESISTANCE PROGRAMS

INTRODUCTION

From 1975 to 1978, there were an average of 5,681 fatal accidents per year on wet pavements, or 13.8 percent of all fatal accidents (2). The National Safety Council reported in the same time frame that data from 23 States indicate that 13.9 percent of the fatal, 19.4 percent of the injury, and 18.6 percent of all accidents occurred on wet pavements (3). Preliminary data from National Highway Traffic Administration (NHTSA) indicate that in 1979, there was a dramatic increase in the number of fatal accidents on wet pavements (from 5,957 in 1978 to 6,928 in 1979). 2/ Fatal accidents on wet pavement accounted for 15.5 percent of all the fatal accidents in 1979.

Nationwide data, developed by the Safety Board (1), indicate that in 1976 and 1977, 13.5 percent of the fatal accidents occurred on wet surfaces while precipitation occurred only 3.0 to 3.5 percent of the time. When the Safety Board compared the percent of fatalities on wet pavement to the percent of precipitation, it found that accidents on wet pavement are significantly overrepresented by about 3.9 to 4.5 times. Therefore, problems created by wet pavement should be of major concern to all States.

The Safety Board's previous study (1) and an accident investigation (4) indicate that accidents may tend to occur on pavements that when wet become more slippery to the motorist than expected. Past Safety Board accident investigations (4)(5) have demonstrated that States may resurface Federal-aid roads with asphalt concrete mixes that do not provide desirable skid resistant surfaces sufficient to ensure a low incidence of vehicle skidding or loss of vehicle control on wet pavements. Other Safety Board accident investigations have shown that a few States failed to maintain surfaces with adequate skid resistant qualities (6)(7)(8)(9).

2/ The total number of fatal accidents increased from 44,435 in 1978 to 45,209 in 1979.

Various traction measuring devices have been in existence for 85 years (12). For 45 years knowledge has existed that a minimum coefficient of friction of 0.3 to 0.4 (skid number of 30 to 40) 3/ was desirable, that aggregates consisting of gritty rather than polished particles are desirable, and that available friction is reduced with increased vehicle speed (14). The importance of good tire tread designs to allow water drainage through the channels in the tire and the improved effects of water flow between the tire and open-textured pavements has been common knowledge for about 40 years (16). The need to calibrate friction measuring devices and to investigate accidents with multidiscipline teams was identified 20 years ago (15). In the last two decades, Federal Highway Administration's (FHWA) single most important accomplishment in the skid resistance area was to make every State aware of the need for some level of attention to skid resistance. Additionally, the FHWA has promoted research on calibration of trailers, standardization of testing procedures and measuring devices, pavement design and aggregate evaluation, seasonal variation in measurements, the phenomenon of hydroplaning, and numerous other areas. For the last 12 years, FHWA has identified the need for skid resistance programs for all public roads, has established pavement design and construction guidelines with specific provisions for skid resistance qualities, and has required that locations with low skid resistance or high accident rates be corrected. More recently FHWA has solicited comments as to the future direction of the skid resistance programs, and has proposed policy changes (11). (See appendix A.)

Presently, Highway Safety Program Standard (HSPS) No. 12, "Highway Design, Construction, and Maintenance," administered by FHWA, requires every State, in cooperation with county and local governments, to have a program that, as a minimum, provides that —

D. There are standards for pavement design and construction with specific provisions for high skid resistance qualities.

E. There is a program for resurfacing or other surface treatments with emphasis on correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces.

The manual (10) for this standard provides guidelines to assist political subdivisions in developing programs. The manual was developed "based on the best knowledge currently available" and was to be updated as research and operating experience provided new insights. The manual provides "recommended minimum interim skid numbers." Road surfaces with a skid resistance value less than the interim skid numbers were to be analyzed for corrective treatment. These are "guidelines" and "interim skid numbers," and specific corrections are not required.

3/ In early studies researchers referred to coefficient of friction. Skid numbers are typically obtained with a skid trailer which was developed in the last 2 decades and conforms to the American Society for Testing and Materials Standard E 274-79. Some individuals use these terms interchangeably, however, the skid number is usually obtained with a specified water and tread depth.

As a result, the standard concerning skid resistance is not as effective as it could be. FHWA headquarters terminated its review of the States' compliance with the standard in 1969 after unfavorable responses were received. Now, each State is asked to report on the extent of its skid resistance inventory in its Annual Safety Report to FHWA. Additionally, FHWA division offices monitor State skid programs periodically (every few years).

Based on the Safety Board's review of State programs and selected responses to the FHWA Advance Notice of Proposed Rulemaking (ANPRM - 42FR58542 - Docket No. 77-16), "Skid Accident Reduction Program" (11), it is obvious that some States are opposed to the establishment of inflexible minimum skid number requirements as a measure of adequate skid resistance. Their opposition results from a number of factors, including:

- o Liability resulting from failure to comply with "a standard of care" characterized by a specific numerical minimum standard.
- o Costs of bringing all older pavement surfaces up to a higher frictional coefficient and maintaining the pavement at that level.
- o Lack of reliable test procedures makes it difficult to determine if "standards" are met.
- o A desire for flexibility to develop and implement programs on a State-by-State basis, because of variables, such as quality and availability of materials within the different States.

The FHWA should review past guidelines and establish a mandatory standards to assure progressive State programs which effectively utilize available resources. The Safety Board is hopeful that this report will guide the FHWA to that end.

PROGRAMS EVALUATION

Existing Federal guidelines, States' responses to the FHWA Advance Notice of Proposed Rulemaking, (11) and the Safety Board's accident investigations were utilized to develop a questionnaire. Using the questionnaire, NTSB officials and FHWA division officials visited selected States and surveyed their skid resistance programs. State safety, pavement design, and research personnel involved in skid resistance programs participated in the survey. In addition to discussing the questionnaire, the Safety Board, accompanied by FHWA division officials examined various State facilities, equipment, and construction projects. Basic topics included in the questionnaire were (1) organizational structure and responsibilities, (2) manpower, (3) equipment, (4) accident record assimilation capabilities, (5) skid measurement procedures and locations, (6) pavement design and construction specifications, (7) pavement treatments used for skid resistance, (8) use of weather data, and (9) miscellaneous . (See appendix B.)

Organizational Structure

Those that have the responsibility for designing, constructing, and maintaining State roads with good skid resistance are usually within several bureaus, divisions, or branches of the State's Department of Transportation/Highway. However, each State's program that was reviewed had its own unique structure that usually included several organizational units. Typically, there was a safety or accident statistics group, a materials and test office responsibile for skid testing, and district offices responsible for specific roads within a specific area of the State. In some States, the materials office was responsible for designing and selecting pavement mixes, while in other States a highway design office had that responsibility. In some States, a single staff member was responsible for the day-to-day operation of a wet weather skid reduction program. In one State, the research office accessed accident data and provided guidance to the materials office, but the safety office was not aware of the status of, or involved in skid program activities.

Skid Programs — Goals, Objectives, Activities, and Evaluations:

The Highway Safety Program Manual (HSPM) No. 12, "Highway Design, Construction, and Maintenance," (10) states that:

> Prior to the implementation of a highway design, construction, and maintenance program, certain steps should be taken to facilitate a comprehensive evaluation.
>
> A. Short- and long-range goals to be met by the program should be established.
>
> B. Where practical, a budget should be developed for each program area.
>
> C. Procedures for performing the evaluation should be developed.
>
> D. A determination should be made of what data will be required and measurement techniques developed.
>
> E. Where available, preimplementation data should be gathered for comparison with data gathered during evaluation.
>
> F. An implementation schedule should be set for the program."

Officials from each of the 10 States reviewed were asked questions to determine if goals, budgets, evaluations, data requirements, and time frames have been defined for skid resistance programs. Replies varied as follows:

Some States have adopted short-range and long-range goals. Some have defined activities rather than specifying goals. Examples of goals include:

Short range : Identify those locations which have wet weather accident rates statistically higher than the Statewide rate.

Improve existing surfaces with low frictional properties.

Improve the frictional properties of newly constructed surfaces.

Improve locations with both a wet pavement accident problem and a low skid number.

Long range : Provide pavement surfaces with acceptable levels of skid resistance throughout their useful life through proper design, materials selection, and construction and maintenance.

Improve the friction of every road to a minimum skid number.

Reduce accidents.

Improve texture of roads.

Examples of activities include:

Inventory roads using a skid trailer.

Investigate accident locations.

States which have goals or objectives have developed various procedures for evaluating when goals are attained. For example:

On specific projects or short-range goals some States use before/after accident data or benefit/cost ratios to determine if the desired results have been obtained.

One State's approach is as follows:

A sample of completed capital projects is analyzed for before and after accident frequencies using statistical tests to determine the significance of the reductions. Benefit/cost ratios are calculated for these completed projects based on the actual results achieved.

> Another procedure for monitoring long range goals is to monitor the skid resistance of a sample of pavement surfaces on the State highway system to determine their performance. Information obtained in this manner can be used to revise specifications for new pavement surfaces in order to ensure acceptable skid resistance, and to evaluate the progress made toward providing surfaces with higher frictional properties.

Most States have not defined time schedules for achieving long-range goals. One reason cited for not establishing long-range goals is the dependency on the availability of funds. These goals could rapidly change due to inflation and other economic factors. Some States have established short-range goals for improving wet pavement accident locations within 1 or 2 years after they have been identified.

Generally, based on the Board's subjective ranking, the more progressive, comprehensive, and dynamic wet pavement programs appear to have established short-range and long-range goals, time schedules, procedures for attaining goals, and procedures for evaluating attainment of goals. These structured programs tend to integrate all the organizational units with responsibility for skid resistance activities and have more funds earmarked for improving wet pavement accident locations on a continuous basis.

Of those States reviewed California and Pennsylvania had the most progressive skid resistance programs. The wet pavement fatal accident index (1) for Pennsylvania is about 50 to 125 percent lower than those of the 10 States with high indexes and California's index is about 50 percent lower than the top three States' indexes. These two States are an interesting comparison in that California officials indicate that they have good aggregate readily available, while Pennsylvania does not. To compensate for Pennsylvania's shortage of good quality aggregates, an aggregate management process has been developed. Other highlights of Pennsylvania's skid program, which used four skid trailers, include: extensive use of accident data and minimum skid numbers, testing of local roads on request, and use of grooving and some open graded material. California, which has three skid trailers, has used open graded mixes and grooving extensively, used weather data extensively to analyze accident data, conducts extensive evaluations of projects, requires a minimum friction level on newly constructed bridge decks, occasionally tests local roads, and has earmarked about $1,000,000 annually for improving wet pavement accident locations. Both of these States appeared to have programs with defined goals and objectives.

Resources — Manpower, Measuring-Devices, and Funds

Because various bureaus of a transportation department have responsibilities for a skid program and the integration of the skid program into the overall highway program of a State, it is difficult to determine the staffing level needed to conduct an effective program. Among the States that did estimate the number of persons directly involved in the skid program, estimates varied from a low of 3 persons to a high of about 50 persons, a range of about 0.2 to 2.0 percent of the total staffing of the respective transportation departments.

All of the States reviewed used one to four locked-wheel skid trailers, which either were manufactured by K.J. Law, Soitest, Cox, or by the State. A previous study (19) documented the capabilities of most machines. The Board found that many trailers had the initial capability to lock either left or right wheels, but the right wheel parts had been utilized to maintain the left wheel. State officials indicated that trailers with digital data recording capabilities simplify data analysis and staffing needs, and to the Board there appears to be a tendency toward the increased use of the digital output trailers.

The States estimated annual cost of operating a skid trailer (including capitalized cost for the trailer, 20 American Society for Testing and Materials (ASTM) tires, calibration, salaries, and travel) to be $40,000 to $125,000. The average miles inventoried in States varied between 2,000 to 7,000 miles annually per skid trailer.

Testing — State Systems Tested and Types of Tests

To understand the extent of skid testing that is being done, the magnitude of the responsibility assigned to the State highway department by the State Government must be defined. In some States, the State is responsible for almost all the roads within the State, while in other States the State is only responsible for Interstate and U.S. and State numbered routes not located in urban areas. While some States do not have the authority to conduct skid tests off the State system, other States try to test a few urban areas or streets annually. Among the 10 States visited, responsibility varied from a minimum of about 7,000 to a maximum of 73,000 miles of roads. In some midwestern States, about 80 percent of the total mileage of roads within the State is not hard surfaced (asphalt or Portland cement concrete) which are usually not skid tested. While the weather allows some States to conduct skid tests all year long, other States are restricted to a few months between late spring and early fall.

In the past, most skid testing has been conducted in conjuction with a Statewide inventory with States conducting from 1 to 5 tests per mile. Some States placed greater emphasis on analyzing high wet pavement accident locations; however, one State found that only about 10 accident locations could be analyzed in a week and that some locations (intersections) took as long as a day to test. Other States place emphasis on research to evaluate pavement designs. The total annual number of test runs varied from 6,000 to 150,000 in the States reviewed.

Accident Record Capabilities

Most of the States reviewed identified accident locations on the State system to the nearest 1/10 to 1/100 of a mile. The Highway Safety Program Manual for Highway Safety Program Standard No. 9, "Identification and Surveillance of

Accident Locations," states that measurements should be made to the nearest 1/100 of a mile. Some of the States cautioned that accident locations off the State system were not too reliable. In one State, the "off-State" system had no reference system, but spot maps were being developed manually using a coordinate system. In another State, State university students were used to code accident locations manually for entry into the computer system. While some States have the computer ability to scan accident segments of variable lengths and to plot collision diagrams, most States do not have statistical programs to identify locations with increasing accident trends, unusual conditions, or other rapidly developing problem locations. Usually citizen or police complaints are needed to call to the attention of officials these types of locations. Part of this problem is due to the delay in entering accident reports into the computer system. Delays of from 2 weeks to 6 months before usable computer data were available were reported by the States, but States where the "highway departments" coded accident reports tended to have smaller backlogs than those States where the enforcement department prepared the computer tapes. One State, with a 2-month input backlog, was not fully utilizing the capabilities of its data to pinpoint high hazard areas since it was only used every other year rather than on a continuous basis. Although many States have computer data which include pavement types, geometrics, skid numbers, sufficiency ratings, and other variables, only two States had the computer systems and accompanying programs required to provide simultaneous comparative analyses of relationships of several files.

Accident Data Versus Weather Data

The Safety Board's special study (1) encouraged the use of weather data in conjunction with accident data to analyze suspected wet pavement accident locations.

Of the 10 States reviewed, 5 indicated that they have not used weather data previously in their program analysis. Three States have used climatological data, one State has used a single station's rainfall data, and one State has used hourly precipitation data. While some States expressed an interest in obtaining hourly precipitation data, three States indicated that the data probably would not be used if it were available.

Two States commented that between 1976 and 1977, the percentage of wet weather accidents increased considerably. In both of these cases, the percent of wet time had also increased. Weather data could help to explain changes in wet pavement accidents. Additionally, weather data could be used in conjunction with accident data to determine locations with above-average or statistically significant wet pavement accident rates so that they can be evaluated and improved.

Skid Measurements and Their Use

Skid Testing.--Seven of the 10 States surveyed indicated that complete skid resistance inventories of all roads either were not useful, were not cost effective, or were not beneficial. Three States indicated that inventories were useful to various degrees --

- One State "feels that if one tort claim is prevented, the $50,000 spent annually on the process is well worth it."

- One State believes "that continued inventories at intervals of 5 years or more would be sufficient, as well as beneficial and feasible."

- Another State indicated that "inventories are useful to some extent," and they are "developing a computer program which will make the inventory more useful in identifying potentially hazardous locations."

In the Advance Notice of Proposed Rulemaking, "Skid Accident Reduction Program," (11) issued by FHWA on November 10, 1977, 14 States not included in the Safety Board's review made comments on the benefits of inventories. Eight States preferred to deemphasize inventories for reasons similar to those previously cited. Six States encouraged continued emphasis on inventories.

Data made available to the Board by one State show the value of investigating accident locations. The data provided were tabulated for inventory, spot hazard, special request, 4/ overlay, and new construction roadway segments. (See Table 1.)

The value of the skid inventory program is illustrated by the fact that 16 percent of the miles inventoried had a skid number below 30. On the other hand 83 percent of the miles tested under the spot hazard location program had a skid number below 30. Therefore, with this spot hazard program 11 percent of the road surfaces with skid numbers below 30 were identified by only 2 percent of the testing. Therefore, this method appears to be an effective way of finding problem locations. Four other States reviewed used a computer list of locations with accidents on wet pavements to define where skid testing should be conducted, with one State conducting testing based almost exclusively on accident records. In the responses to FHWA's ANPRM 6, other States suggested that more emphasis should be placed on using accident records.

Some States stated that they had no evidence of new roadway designs which give poor performance though occasionally a construction problem results in poor performance that is found upon inspection. In some of these States, no effort has been made to collect data on new surfaces other than by visual inspections. Even with existing technology, within 45 to 60 days after construction one State's overlay and new construction testing found 12 miles of road with skid numbers less than 29. Although the 12 miles represented only six-tenths of 1 percent of the new pavements, it illustrated that some new pavements do not provide good skid resistance. An additional 28 percent of the new surfaces constructed in this State

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4/ In this State, spot hazard means a location with a high incidence of wet pavement accidents and special requests means tests for individuals of specific locations suspected of having a problem.

Table 1.— Value of Investigating Accident Locations

No. of Miles of Roadway by Testing Category

Skid Range	Total Miles	% of mileage in range	Inventory	% in range	Spot hazard	% in range	Special request	% in range	Overlay	% in range	New construction	% in range
0-9	0	0	0	0	0	0	0	0	0	0	0	0
10-19	25	0	14	56	11	44	0	0	0	0	0	0
20-29	1398	15	1221	87	148	11	17	1	9	1	3	0
30-39	3154	33	2412	76	21	1	118	4	371	12	232	7
40-49	3520	37	2314	66	4	0	82	2	897	25	223	6
Over 50	1333	14	908	68	8	1	2	0	335	25	80	6
Total % miles	9430	100	6869		192		219		1612		538	
% of total Miles				73		2		2		17		6

Categorization by Skid Number less than 30 or by 30 and over

Skid Range	Total Miles	% of mileage in range	Inventory	% in range	Spot hazard	% in range	Special request	% in range	Overlay	% in range	New construction	% in range
Under 30	1423	15	1234	18	159	83	17	8	9	1	3	1
30 and over	8007	85	5634	82	33	17	202	92	1603	99	535	99
Total miles	9430		6869		192		219		1612		538	

had skid numbers in the range of 30 to 39. In such cases, new surfaces may warrant correction regardless of the wet pavement accident history. This State corrects new pavements with skid numbers in the 30 to 35 range before wet pavement accidents occur.

Other States follow a policy of monitoring new pavements. One State tests every new pavement before the end of the calendar year; another State tests within 3 to 4 months after the surface has been placed; and one State has been required by the FHWA Division Office to skid test all pavements 45 to 60 days after they have been placed (same State as the data from Table 1). This FHWA division instituted a policy wherein Federal funds for a project are withdrawn unless certain skid resistance values are attained. This policy was formulated mostly because of the lack of good aggregates within the State. In the State subject to this policy, testing is conducted by the State as soon as practicable to obtain complete Federal reimbursement.

Another State was especially concerned with the low skid resistance of new pavements when first placed. The State found that the "initial break-in period" (perhaps to wear off the asphalt coating to expose the surface of the aggregates) is about 1 year for its most commonly used mix. This time period would depend on traffic volumes, and this State has low volumes. In this State, "SLIPPERY WHEN WET" signs are put in place for 1 year or until a skid number of 40 is obtained when tested at 40 mph. Since signing can reduce speeds slightly (41), this practice is a good one, especially since motorists do not expect pavements to be slippery where no sign is posted on a new pavement. Since on new riding surfaces motorists may tend to increase speeds and drive less cautiously, the practice could be even more informative to motorists if an advisory speed plate is added. Prior to the adoption of the 55 mph speed limit, limited research (42) had been conducted on wet weather speed zoning. This study basically relates to 70-mph roads and there would thus appear to be a need to conduct similar research for roads with 25 to 55 mph speed limits. On one construction project in another State, orange "SLIPPERY WHEN WET" signs were put in place. The orange sign would be especially useful when tack coats and various other lifts are being applied since they can reduce texture and perhaps result in a very slippery surface.

It is possible that the "initial slippery break-in period" has not come to the attention of State highway officials because of the limited exposure time or backlogs in accident data reporting (up to 6 months). By the time a location is reported to be experiencing a high number of wet pavement accidents, the friction may have improved due to wear and the slipperiness, therefore, is no longer detectable. Initial monitoring of surfaces is probably warranted in those States which have not conducted this type of testing previously to determine if a practice of using warning signs on new pavement is needed.

Continuous evaluation of new pavements, including materials, design, and construction practices, should allow for prediction of surface performance on other new roads in the future. This would facilitate the practice suggested in the Safety Board's (11) response to FHWA regarding its ANPRM on "Skid Accident Reduction Program," that "new surfaces after an initial period of break in, should be required to be skid tested before final payment is made to contractors." Currently, one State uses a portable tester to test Portland cement concrete before the pavement is opened to traffic, but not sooner than 7 days after concrete placement.

As a result of an accident investigation in Oklahoma (4), the Safety Board recommended that the FHWA:

> "Develop expeditiously procedures to determine the skid resistant characteristics of newly constructed and resurfaced roadways before they are opened to the public. (Class II, Priority Action) (H-78-19)"

The FHWA responded by stating that:

> "Because of the problems with evaluation of the friction properties of a new pavement, the FHWA proposes an alternative to the NTSB's recommendation. This alternative is considered adequate to accomplish the NTSB's and FHWA's intended goal of ensuring high skid resistant surfaces and reducing wet weather skid accidents.
>
> The FHWA is in the process of making program policy modifications which will increase emphasis on the reduction of wet weather skidding accidents through:
>
> 1. Updating of FHWA policy in FHPM 6-2-4-3 (IM 21-2-73) to reflect the latest technology.
>
> 2. Requiring the States to:
>
>   a. evaluate pavement designs and surface treatments for skid resistance characteristics,
>
>   b. annually develop a list of wet pavement accidents, locations investigated, and corrective actions taken,
>
>   c. incorporate skid condition of pavements into the State's capital improvement program or schedule of construction projects, and
>
>   d. prequalify aggregates for pavement wearing surfaces through a combination of standard tests.

3. Establishment of a closer working relationship between FHWA and the States (and local agencies) regarding pavement resurfacing programs conducted with State and/or FHWA funding.

Existing technology enables engineers to predict probable in-service skid resistance properties of mixes designed and constructed with certain combinations of materials and procedures. Through this "fingerprinting" (prediction) technique, pavement wearing surfaces which may provide marginal or inadequate skid resistance can be avoided. Failures that may affect the skid resistance of a new surface can be detected by existing quality control procedures and verified, if needed, by current friction testing methods."

This policy is basically the same as that stated in FHWA's most current NPRM on skid resistance (36).

Since new or overlayed pavements are usually designed to last for about 5 years or more, the Safety Board believes that once the initial thin coat of asphalt has worn off the aggregates, and if the pavements no longer provide good skid resistance, these pavements should be improved as soon as possible. This should reduce many skid related accidents especially since a new smooth riding pavement may be extremely deceptive to the motoring public.

In the past, periodic skid testing has been conducted by most States during inventories only. While some States have inventoried interstate and primary routes only, other States have tested all their State routes several times. Some States continue to inventory all of their system each year while other States test wet pavement accident locations and monitor the performance of various types of mixes. The Safety Board's Special Study (1) and some of the data compiled by the States do not support the need to routinely and randomly test interstate routes. While accident statistics for the interstate routes should be monitored to identify specific high accident locations, greater emphasis should be placed on primary and especially secondary roads where funding limitations require establishment of priorities.

One State provided the following data which illustrate the need for this emphasis:

Table 2.—Wet Pavement Accidents by System

Highway Type	No. of wet accidents by highway type	Wet accidents by highway type vs. all accidents by highway type (Percent)	Wet accidents by highway type vs. all wet accidents (Percent)	Highway mileage by highway type (Percent)	Highway travel by highway type (Percent)
Interstate	521	7.78	5.81	1.74	30
Primary	3,365	9.65	37.55	14.98	49
Secondary	5,076	17.50	56.64	83.59	21
Statewide average		13.00			

In this State, 57 percent of the wet pavement accidents occurred on secondary roads, which comprise 84 percent of the mileage in the State and carry 21 percent of the traffic. On this system, where more than 17 percent of the accidents occurred on secondary roads with wet pavement, the State had inventoried only a few miles of these roads; however, considering the mileage involved on this system and the relative amount of inventory required, an inventory of primary roads would possibly prove more beneficial.

In the Board's special study the percentage of wet weather accidents on interstates was significantly underrepresented, whereas other U.S. and State routes were overrepresented. Therefore, since interstate roads do not appear to have a systemwide wet pavement problem emphasis should be placed on testing interstate roads only at potential high accident locations.

A response to FHWA's NPRM (36) suggested that low-volume roads should not be treated the same as interstate highways. The FHWA agreed with this but recommended ". . . that all roads have some type of pavement with skid resistant qualities." As the Board noted in its special study, statistically, fatal accidents on wet pavement in the 48 contiguous States occur less often than expected on interstate and county roads. This type of accident information can provide overall program direction, but must be analyzed carefully to identify specific problems. For example, curves on a county road may require a higher friction coefficient than a straight, divided, interstate road; also, interstate interchanges may require a higher coefficient of friction than other interstate segments.

The systems utilized by the various States to select locations for periodic skid testing vary considerably. Some States use a random sample basis, deleting for 1 year segments tested the previous year that had high skid numbers. Another State selects sites that represent all possible combinations of aggregates and mix designs. Other States indicated that segments are tested if 8 or more accidents occur in a year on wet pavement and if wet pavement accidents account for 25 to 30 percent or more of all the accidents. Nearly all of the 10 States indicated that they tested special request or "complaint" locations.

Skid Number, Mix Design Correlations - Test Speeds For Skid Trailers.--None of the States indicated that mix design and skid numbers observed in other segments were used to predict the skid number of untested locations or to determine critical locations, although this practice has been advocated by FHWA for about 10 years. Most States have periodically skid tested various combinations of mix designs and aggregate for different levels of traffic. Some States have compared the different construction procedures with skid numbers and have used this information to evaluate designs, to select the design and aggregate specifications for overlays and new pavements, to provide higher-than-normal durable frictional surfaces where warranted, and to eliminate undesirable mixes. This type of analysis, which makes full utilization of skid testing data, is encouraged.

Many States have conducted skid tests at different speeds to develop speed gradients on surfaces but usually only in conjunction with research projects. Two States indicated that speed gradients may be of limited value and that they are not always consistent and repeatable. The Safety Board reiterates its position that "roads be tested at or near posted speeds." This should eliminate the need for extrapolation of skid values based on assumed gradients. Additionally, if certain mixes are evaluated at different speeds, testing might better stratify the performance of mixes and define the speed level for which various mixes should be used.

Eight States conducted tests at 40 mph; one State at 55 mph, and one State at the operating speed of traffic — up to 65 mph. One of the States indicated that it occasionally sampled roads at 55 mph. Other States ran tests at the speed limit in areas with speed limits less than 40 mph, and ran gradients both at accident sites and in conjunction with research projects. Another State indicated that it ran many tests in urban areas at night to permit for safe testing at higher speeds.

Calibration.—Before October 1, 1978, the FHWA funded the skid trailer calibration centers in Texas and Ohio. From October 1, 1978, to March 1980, the centers were funded by charging about $8,000 to the owner of each trailer calibrated. FHWA has now completed negotiations with the Texas center and the Ohio center; FHWA will monitor the contracts with the centers, but will be reimbursed by the States for each trailer calibrated. The States have the option of using 100 percent Federal Highway Planning and Research (HPR) funds (or Section 402 5/, State funds) for calibration costs.

At least 5 of the 10 States reviewed by the Safety Board believed that the Federal Government should fund the centers directly. Some of these States indicated that this could be one of the most important contributions FHWA can make to systematic skid testing. Three other States indicated no problems existed as long as HPR or 402 funds were available. Two States advocated the use of a "roving" calibration crew to reduce the frequency of visits to calibration centers, possibly in conjunction with the National Bureau of Standards.

5/ Funds authorized for development and implementation of manpower training programs and for demonstration programs. At least 40 percent of all funding in this program is earmarked to go to local programs.

The importance of Federal funding for the centers was emphasized in the reviews. One State had all of its trailers calibrated at a center in 1978 to take advantage of Federal funds. In 1979, when Federal funds were not available only half of its trailers were calibrated at the centers. Another State indicated that it did not have funds for recalibrating two trailers that normally would have been scheduled to go to a center in 1979. Finally, one State indicated that "since the centers started charging such exhorbitant prices, they will calibrate at the center less often." Although calibration every other year may suffice (21), these States' attitudes toward calibration show the difference Federal funding can make.

Fifteen States addressed the calibration issue in their response to FHWA's ANPRM (11). Four States urged FHWA to provide Federal funding; five States urged FHWA to maintain the centers; two States stressed the need to allow the use of HPR and 402 funds; and four States questioned the cost effectiveness, the cost and time of calibration, and the need for centrally located or "roving" calibration crews.

Many of the 10 States surveyed expressed concern that since they maintained their own trailers, their trailers were in the centers only 3 days; whereas, other State's trailers were in the centers up to 7 days, but paid the same fee. Those States with air-bearing force plate equipment indicated that they calibrated their trailers every 30 to 60 days and before testing accident locations that might involve law suits. The States with such equipment indicated that they usually maintained their equipment and were completely calibrated within 3 days at the centers.

Based on the Safety Board's experience and a review of ANPRM responses, the Safety Board concludes that many of the States do not support the calibration centers. Nevertheless, without these centers States cannot be assured of consistent, accurate results. Therefore, the Safety Board believes that the FHWA should require that skid trailers are periodically calibrated and should initiate rulemaking. Complete funding of the centers by FHWA would probably be necessary if calibration is made mandatory.

The Safety Board believes that the establishment of the FHWA-sponsored calibration centers has made a substantial contribution to skid resistance programs, and in its response to FHWA's ANPRM (11), it supported the continued operation of FHWA calibration centers. Calibration assures consistent, accurate results within a State and allows the exchange of compatible information between States. This exchange of data will be more important as resources become more scarce, and States must also evaluate the need to import aggregates from other States. The Safety Board has observed the importance of calibration in three of its highway accident investigations (4,5,6) where two or more trailers were used to measure skid resistance. In one accident investigation (4), an uncalibrated trailer measured differences in skid number varying by about 10 numbers when compared to measurement with a calibrated skid trailer. In two other accident investigations, values were similar. Without periodic calibration and correlation with an area-reference skid measurement system, large discrepancies can occur in the measurement of surfaces. The Safety Board believes FHWA should review its policies to determine the effectiveness of the various funding strategies and to determine if complete Federal funding, as was provided before 1978, might encourage calibration.

Skid Numbers Versus Accident(s)/Rates.—At the present, there is no universally accepted relationship between skid numbers and accident rates. Most studies and many of the States reviewed indicated that there is either a weak correlation or no correlation between skid numbers and accidents or accident rates. On the other hand, two States indicated there was some relationship, with one of the States specifically stating that where skid numbers are above 40 the ratio of wet to dry accidents drops considerably. Another State suggested that a high correlation exists between surface texture and wet weather accidents (20). Also the Safety Board's special study (1) stated that "there is circumstantial evidence that the performance of a roadway when it is wet may be related to the surface materials used to construct the roadway and to the mix design characteristics."

Nevertheless, the Safety Board's accident investigation experience has shown that most accidents are caused by a combination of human, vehicle, and environmental factors, and that there are many factors besides low skid numbers which often contribute to wet pavement accidents. (See Table 3.) Without accounting for these variables, accident data cannot be correctly analyzed or interpreted.

For example, the accidents investigated by the Board indicate the importance of friction, texture, tire tread depths, speed, brake balance, and to a lesser extent other factors in wet pavement accidents. When a poorly maintained vehicle (poor tread depth, perhaps unbalanced brakes) approaches a marginal pavement segment (low skid resistance, poor drainage) at an excessive speed, an unstable condition exists where the slightest correction in steering, acceleration, or braking could result in an accident. Other more encompassing accident studies (20) have supported these findings. Future data-gathering efforts should collect this type of information so that future accident data analyses (studies) can be more effective in understanding the relationship between the various factors, and wet weather accidents.

Wheel Tracks.—Studies (24, 25, and 26) demonstrate that differences can exist between the two wheel tracks in a lane. Other studies have shown that a differential in friction between wheel paths could cause a braking vehicle to rotate (22). Concern for this problem was first expressed by the Board in its response to FHWA's ANPRM (11) and elaborated on in an accident investigation report (5). As a result of this accident, the Board recommended that FHWA:

> Evaluate the procedures used in the Safety Board's investigation of this accident for possible inclusion in FHWA guidelines for determining the frictional quality of pavements during pavement inventory programs. (Class II, Priority Action) (H-79-7)

Part of this recommendation dealt with the need to modify inventory procedures to include the testing of both left- and right-wheel tracks.

FHWA responded as follows:

Table 3.--Potential Factors Identified in 12 Accidents[1/]

Highway Factors	
Skid Numbers	
40 or above	2 (1 not measured)
30-39	1
30 or less	8
Poor drainage of water into catchbasins	1
Texture depths of 0.007 inches or less observed	5 (only 5 measured)
Rutted pavement	3
Dense mix design (low air voids)	1
Lack of crown	1
Split coefficient of friction	1
Visible flushing/bleeding	3
Aggregates suspected to have polished	2
Need for greater superelevation	2
Vehicle Factors	
Low tire tread depth (less then 2/32 inch)	4
Inoperable brake/brakes (brake unbalance)	2
Commercial tire/pavement interface	2
Mix of antilock and lock brakes/systems	2
Human Factors	
Driver error	2
Driver input	2
Alcohol involvement	1
Excessive vehicle speeds	4
Driver inexperience	2
Other	
Hydroplaning suspected	2

1/ [illegible] 12 accidents are not statistically significant.

The issue of right-wheel testing capability is admittedly complex. As was pointed out in the response to H-79-7, the studies of right vs. left-wheel testing have not produced consistent findings. Since the cost to provide such a capability is high and most agencies are equipped to test one-wheel track only, we are reluctant to require additional expenditure.

The NTSB investigation at the Scipio site (5) revealed varying friction levels between the left- and right-wheel tracks. However, this evidence did not lead to definite conclusions about the probable cause of the accident. Similarly, we have not found evidence that such a differential is a significant accident problem. We remain unconvinced that testing both wheel tracks is practical for inventory purposes.

However, we will consider advising the States that FHWA favors having skid testers equipped to test both wheel tracks and that such testing is advisable when investigating high accident sites. During routine inventory only one-wheel track testing is standard, but both may be tested if a difference is apparent. We will continue to allow Federal-aid funds for skid testers with the capability of testing both wheel tracks.

The American Society for Testing and Material Standard E274-79 advocates, and most States conduct, testing in the center of the left-wheel track of a traffic lane of a highway. Of the 10 States reviewed, 9 States tested the left-wheel track and 1 State tested the right-wheel track. Two States had one or more trailers with right-wheel capability, and one State used one-wheel trailers which would require repositioning of the test wheel. Several States bought trailers with dual wheel capabilities, but used the right-wheel parts to replace worn parts on the left-wheel system. The various reasons offered for testing only the left-wheel track included:

- o The driver of the test vehicle could see if the water flow was working in the rearview mirror.
- o The left-wheel track is believed to be the most slippery because of passing maneuvers on the track, thus giving the track more exposure.
- o The right-wheel track could be contaminated by dirt from the shoulder.

In two States, the rutting depth in the wheel path is measured. Both States found rutting was worse in the outside (right) wheel path. The greater right track rutting was found to result from lack of stability near the edge of the pavement.

Rutting may indicate that the surface is compacting. During compaction, larger aggregate particles may be reoriented so that their larger aggregate faces are aligned with the surface. If the aggregate is susceptible to polishing, this can lead to rapid degrading of skid resistance (23). If this process takes place, the right-wheel track could have less traction.

In response to FHWA's ANPRM (11), Wyoming, which uses a Mu-meter to test skid resistance, stated that one of the two reasons it did not test the left-wheel track is because it "made a survey on roads with poor friction and the results indicated that on these roads the right wheel path had as much or even more wear than the left wheel path."

In a California research project (24), the following observations were made:

> In California, after limited testing and observation, we have contended that more pavement polishing occurs in the right wheel track of highways.
>
> Results of this investigation show that the left wheel track has lower values than the right on some two-lane roads and on most inner lanes of multilane roads. The right wheel track has lower values in the outer (truck) lanes of multilane roads and on many two-lane roads as well.
>
> Because the skid numbers in the outer lanes of multilane roads are generally lower, it is recommended that we continue to obtain routine tests in the right wheel track. In areas where the left wheel track appears to have a lower skid number and where a definite friction differential seems apparent to the skid test operator, the left wheel track should be tested.

Another study (25) reported that "a sample of 49 test sections was taken from two-lane highways and the average coefficient of friction compared between the outer and inner wheelpaths for each test section. No significant difference was found between the wheelpaths which averaged 0.413 for the outer and 0.419 for the inner."

A Virginia study (26) showed frictional variation in a cross-section of roadway, as measured by a British portable tester and concluded that the coefficient of friction was not constant across a highway surface. The data in this study show that differences do exist and can be observed visually between wheelpaths and especially in areas of bleeding.

If future emphasis is placed on State evaluation of accident locations, the State should have the capability to examine both wheel tracks. In areas with curbs or unusable shoulders, a skid trailer with only a locking left wheel would not be usable for testing right-wheel tracks. Likewise, a testing vehicle with right wheel capability would not be usable for testing the left wheel path unless the vehicle can safely cross the centerline or straddle a lane line. The Safety Board believes that States should obtain skid trailers with the ability to lock either wheel and these should be fully maintained.

Testing Tire-Tread Depth.—The current ASTM standard E501 provides that a skid test tire must have a tread depth when new of about 11/32 inch and can be used until the wear indicator is exposed (at about 5/32 inch).

Five of the 10 States surveyed commented on testing with smooth tires. One State has conducted testing with smooth tires at accident locations and has found that "a smooth tire can better reflect the qualities of a mix . . . .The smooth tire shows an improvement after grooving and correlates better to accidents."

Another State indicated that "a smooth tire will better reflect the texture of the pavement," but "if higher speeds are used for testing, a ribbed tire should be used." Two other States expressed support for changing to, or researching more extensively with, a tire with less tread depth, but expressed caution that perhaps too much research has been completed using the standard tire. One State believed that the existing ASTM tire and tread depth should be kept.

In the response to FHWA's ANPRM (11), two States raised concerns about tread depths. One State advocated the use of the ASTM E-524 smooth skid-test tire (ASTM E-524). For some time, this State has investigated the relationship between hydroplaning-type accidents, pavement texture, and skid tests using both smooth and ribbed tires under its on-going FHWA-sponsored research project. The State stated, "It is well known that a smooth tire is vastly more sensitive to pavement texture than the ribbed tire. Limited data, at this time, suggest that there is a correlation between low skid numbers obtained with a smooth test tire and a high frequency of hydroplaning-type accidents." The State's studies have "shown that a difference of as much as 40 skid numbers may exist between tires on some of these areas where macrotexture is extremely poor and rainfall very heavy. Flooding of the surface may result, tending to negate the effects of treads on vehicle tires. This type of surface condition may be detectable with the use of a smooth tire."

Most States require vehicles to have tire tread depths greater than 2/32 inch. Futhermore, studies (20, 25), in conjunction with wet pavement accidents, indicate that about 15 percent of the vehicles have one or more tires with 2/32-inch tread depth or less. In traffic and safety matters, most designers try to accommodate at least 85 percent of the driving public. This philosophy is used for posting speed limits and in some human factors areas. Therefore, the Safety Board believes that the tread depth used on test tires for skid testing should be reevaluated to determine if existing standards for skid testing should be revised to better approximate the condition of tires actually used.

Texture, Drainage, and Other Testing.—A partial list of factors that should be examined at wet-pavement accident locations was included in Table 3. Collectively, the States surveyed added the following list of factors which they have observed at wet pavement accident locations:

- o Geometrics (horizontal and vertical alignment deficiencies which increase the demand for friction).
- o Inadequate storage lanes for turning vehicles at traffic signals; these do not allow vehicles to get out of through traffic lanes which may result in a rearend accident.
- o Inadequate sight distance which may not provide the required stopping distance when the pavement is wet.
- o Too short a phase on traffic signals which may not provide sufficient time for stopping if the pavement is wet.
- o Inadequate advisory warning of a stop situation that would require additional stopping distance when pavement is wet.
- o Improper traffic channelization that may be confusing, especially during rain when visibility may be reduced.

Additionally, one of the States reviewed has studied traffic data, such as estimated travel speeds, volumes, and congestion, to determine demands for friction. Many States indicated that they examined drainage and texture using various procedures, such as sand patch tests, outflow meters, and other methods. One State indicated that it did not believe that the many types of texture measurements yielded good results and, therefore, preferred to run speed gradients with skid trailers.

Even though some States maintain rutting data, none of the States had determined correlations between rutting and accidents. One State believes that if rutting is a problem a procedure should be developed to determine the advisory speed which should be posted. Future studies should correlate rutting data as part of wet pavement accident analysis. New methods being sponsored by FHWA for obtaining rutting data are currently being evaluated. The Southwest Research Institute is developing a vehicle which will have the capability of measuring topography. A computer analysis of the data collected by this machine should reveal rut depths and areas on the roadway where water is likely to pool.

Pavement Designs and Construction

Skid Standards for New Designs and Evaluations.--All States reviewed indicated that that they incorporated skid resistance standards or the best technology available in new pavement designs. Some States are more restrictive than other States in that only 2 to 4 different proven asphalt frictional courses are approved for the wearing surfaces on all roads. Other States require their best type mixes (usually open graded) on high volume roads. Some States, however, only use a few mixes that have not caused significant problems in the past. Most new Portland cement concrete designs for skid resistance include provisions for surface textures and some States place restrictions on silica sources. While some States require local jurisdictions to adhere to State specifications, in other States, local jurisdictions generally follow State standards. Additionally, one State commented that it was not aware of what its local governments were doing.

Nine States surveyed indicated that they were designing or testing mixes at the expected operating speeds of traffic. The one State that was not, indicated that "speed is not a factor in the design of pavements." Some States indicated that they used only a limited number of proven mixes on high speed, high volume roadways. One State also required higher frictional pavements at intersections and on curves where the demand is greater. A few States use open graded mixes on the high volume, 4-lane asphalt highways. One State noted that the gradient tests that it conducted on samples of mixes were used to predict performance of roadways at operating speeds.

Most States indicated that evaluations of current pavement designs and construction and maintenance practices are performed to insure that skid resistant properties are suitable for the traffic needs. Some States monitor only a sample of some designs and keep records on their performance; other States monitor all new surfaces initially and keep long-term records on only a sample of surfaces. One of the best systems reviewed by the Safety Board uses the computer to store skid numbers (see Table 1), accident records, mix design classifications, and aggregate sources; this provides opportunity to monitor all facets of pavement performance. One State indicated that it was getting adequate friction with its present design and that it was as durable as could be expected, therefore, no evaluations were underway. However, the State indicated that new pavements are monitored and if problems appear, corrective action is taken.

In some States, the skid testing results, including gradients, have been used to eliminate some types of mixes and materials which have not performed satisfactorily. One State has eliminated certain aggregates from use, while other States have eliminated or have modified the mix to correct problems. Another State has established policies to identify corrective measures to be taken if new pavements do not provide desirable frictional qualities.

Many of the States indicated that the mixes they typically used degraded by less than 15 skid numbers during the design life of the pavement. Several States believed that an aggregate in the pavement can be polished only to a certain frictional level, and then it will maintain that frictional level with no further deterioration. One State indicated that any appreciable loss of skid resistance on asphalt pavements is usually because of an excess of asphalt. Based on one State's experiment with its materials, it found that if a pavement was designed for a high skid number (50 to 60), it would deteriorate significantly during its life expectancy and would have more of a potential for a lower or split coefficient of friction. Therefore, this State designed mixes to provide skid numbers in the high 30's to 40's and to remain in that range during their service lives. This approach should be considered by other States.

An FHWA NPRM (36) proposes that in the design of skid-resistant pavement surfaces, each agency should—

> ". . . include an integrated process which combines aggregate quality testing, mix design, and construction quality control with knowledge gained from skid inventories, accident studies, pavement performance evaluation studies, and available technical materials. . . ."

The NPRM also proposes that for pavement designs, each agency should make--

> "an analysis of performance based upon vehicle skidding accident history".

The Safety Board believes that this FHWA approach could gradually improve the system if all resurfaced pavements are provided with a good skid resistant aggregate that maintains that property throughout the design life of the pavement.

Aggregates.--In an NPRM (36), the FHWA stated that "aggregate used shall be from acceptable prequalified sources or subjected to acceptable qualification tests prior to incorporation into roadway surface." The NPRM refers to the American Association of State Highway and Transportation Officials (AASHTO) "Guidelines for Skid Resistant Pavement," which suggests the use of an acid insoluble residue test with the British-Polish stone value and petrographic analysis; however, the AASHTO guidelines do not establish an unacceptable value.

The 10 States generally rated aggregates within the State from good (4 States) to poor (1 State). Four States indicated that they had imported aggregates from neighboring States. Four other States indicated that in some areas of their State they had to transport aggregates from within the State as far as 100 to 200 miles. Some State engineers indicated that strong, local aggregate lobbyist organizations had often made it difficult, if not impossible, to persuade management officials to allow the importation of aggregates from outside the State. One State indicated that it has had two good natural sources of aggregates, but its supplies are being exhausted. A State in which the only usable aggregate is river gravel has not been successful in crushing it uniformly. The uncrushed aggregate produces an unstable mix because the material in the mix can move. A few of the States indicated that they had trouble with some limestone deposits because some limestone tends to polish. One State indicated that good skid resistant aggregates available in the State are not hard, sharp particles, but are weakly cemented sandstone and are used as necessary. Some States are using or importing by-products from manufacturing such as slag (steel) or fly ash (electricity), while others are using manmade products, such as lightweight expanded clay, shale, or slate. Since the manmade products require large amounts of energy to manufacture, their use in the future may not be practicable.

Four States indicated that they do not rate quarries, while the other six States did evaluate aggregate sources to various extents. Two of the States that did not rate aggregates believed that their aggregates performed satisfactorily. The other two States indicated that they know where good aggregates are to be found. Five of the States rate quarries, and four of the five develop lists of approved sources and make the lists available to other jurisdictions. One State routinely accepts aggregates which reportedly have been proven to perform as desired, while aggregates from other sources are required to pass a number of tests before they are classified as acceptable. Of the States that rate quarries, one State allowed the blending of good aggregates with unacceptable aggregates to produce a skid-resistant wearing surface; another State expressly prohibited the practice.

Every State indicated that it ran tests on aggregates. The tests included:

Test	No. of States
Los Angeles abrasion test (wear)	10
Fractured face count	7
Acid insoluble residue test	6
Petrographic analysis	4
Soundness	4
British-Polish stone value	2
Freeze thaw test	2

Other tests included the presence of deleterious particles, colorimetric tests, film stripping, centrifugal kerosene equivalent tests, and specific gravity measurements.

The acid insoluble residue test is considered "a useful evaluation tool when used in conjunction with field performance for a given aggregate source, or when combined with other indicative laboratory polishing tests (30)." It is used for evaluating limestones and dolomites. This test uses hydrochloric acid to dissolve carbonate material to determine the silica and other hard particle contents that contribute to skid resistance. While one State limits uses of aggregates to those with 35 percent residue or more, another State allows the use of aggregates with only 12 percent residue. One State does not use this test since all aggregates were found to have less than 15 percent insoluble material. In one study (31), a researcher concluded that an "increase in portion of insoluble residue gave only general trends of increase in skid resistance. Further tests are needed on samples that will cover narrow intervals in the range of 10 to 35 percent insoluble residue content."

While some of the aggregate tests are measures for predicting skid resistance properties (acid insoluble, British-Polish stone value, petrographic analysis, and others), other tests are typically measures of durability. For example, the "Los Angeles Test does not necessarily have any relationship to polishing of aggregate under traffic wear" (39). Aggregate evaluation is an important phase of a skid resistance program. The Board's survey shows the variety of treatments and values within States. The Board's response to FHWA's NPRM (36) stated that: "The FHWA should identify specific tests that qualify an aggregate and should try to define levels for acceptance or rejection of the aggregate source, perhaps for various levels of traffic."

Texture.—Although most States have realized the importance of pavement surface texture, and research (20) has shown that accidents tend to occur on pavements with low texture depths, few States have established minimum standards. Also, research sponsored by FHWA (32) has identified minimum desirable standards. France has gone as far as to establish minimum recommended levels of geometric roughness evaluated by the sand patch test (33). The Board's accident investigation experience has shown texture is important, and specifications should be adopted for acceptance of all new surfaces. Previously, the Board recommended that the FHWA:

> "Develop expeditiously procedures to determine the skid resistant characteristics of newly constructed and resurfaced roadways before they are opened to the public. (Class II, Priority Action) (H-78-19)"

In correspondence regarding this recommendation, the Safety Board suggested that a texture depth requirement could fulfill a part of the intent of this recommendation. FHWA has responded by indicating that it "will consider the findings and suggestions resulting from review of wet-weather safety."

Some designers and researchers believe that an open-graded mix, if properly designed and constructed, is one of the best methods known to construct an asphalt pavement with good texture. Of the 10 States reviewed, 8 have used open-graded mixes. The other two States, both from the same geographical location, have constructed "modified" open-graded mixes, and one indicated that it did not have good crushable aggregates available to compose a "true" open-graded mix. While one State has 10,000 miles of open-graded mix in place, another State has used this mix at limited locations on an experimental basis. Four States indicated that they had favorable results with open-graded mixes while only one State did not. Three States indicated that open-graded mixes were of value at certain locations such as on curves with a high wet-weather accident history. One State believes texture is extremely important so it uses very open mixes. While most States restrict the overlay depths to 5/8 to 3/4 of an inch for open-graded mixes, a couple of States use depths up to 1 inch. One southern State indicated that depths of 1 inch tend to allow the asphalt to puddle, and therefore, it has reduced the design thickness. A couple of States indicated concern that these mixes get denser over time, that their surfaces are covered with ice differently, that they require more salt to deice, and that they are harder to maintain. While these may be of legitimate concern, a study (16) tends to deemphasize or dispute most of these comments. One State believed the reduction in water spray on this type of pavement was important. Another State indicated that this mix should be used adjacent to paved shoulders to provide the best drainage. Finally, one State noted that open-graded pavements did not perform well in areas exposed to tire chains. All the States indicated that when an open-graded mix is used, the design of the surface course is independent of the underlying base or binder course. Thus, the open-graded surface treatment is considered as an "extra" layer and is not considered to increase the stability of the structure. In its ANPRM response (11), one State expressed concern about durability of pavements which have open-graded surface courses covered by another overlay.

On new Portland cement concrete (PCC) surfaces, all States reviewed required tining to provide a texture. There is a tendency toward favoring longitudinal tining rather than transverse tining because of the simpler construction process. The spacing of the grooves varies from 1/2 to 3/4 inch apart with grooves that are about 1/8 by 3/16 inch in cross section. On old PCC surfaces, 7 of the 10 States use grooving. The number of miles of grooving varies between 2,000 miles in one State to only a few miles in other States. Two of the States do not groove pavements because grooved pavements maintain satisfactory performance for only a short period of time because of wear from studded tires. One of these States believes that the use of studs defeats grooving benefits by prematurely wearing the pavement until no grooves exist. The other State was unable to groove pavements economically because of its extremely hard aggregate. One State has grooved asphalt, but maintains that it tends to close in 1 to 2 years, although one location is intact after 10 years. One State that has grooved at many locations reported that grooved pavement reduced wet pavement accident rates by about 70 percent (34). However, grooving after construction is expensive and is commonly done only to correct wet pavement accident locations. A couple of other States have milled Portland concrete cement surfaces to increase texture.

In the Board's response to FHWA's NPRM, it stated that:

> "The Board's final concern with the proposed rulemaking is that even though this document is supposed to address design, there is no specific reference made to texture, in either asphalt or Portland cement concrete (P.C.C.) designs. Existing research on P.C.C. tining supports more positive guidelines at this time. Also, the Safety Board has addressed the need for texture in several reports, and simultaneously cited French texture requirements and FHWA-sponsored research studies which express recommended texture minimums. Perhaps research sponsored by the FHWA in the United States has not sufficiently highlighted what the minimum texture measurements should be for asphalt pavements. The FHWA should place emphasis on this area to be able to address this subject in the future. As a minimum, the rulemaking should address texture . . . ."

Dense-Graded Asphalt Mixes and Design for Void Ratios.--As a result of an accident investigated by the Safety Board (5) and the Asphalt Institute's recommendation that a minimum void ratio of 3 percent be used (35) since low void ratios "may result in instability or flushing," the Safety Board became concerned with design void ratios in asphalt mixes. The Board's 10-State survey revealed that 6 States designed mixes with air voids of 3 percent or more, 2 States designed mixes with air voids of 2 percent or more, 1 State allowed air voids as low as 1 percent, and 1 State did not measure air voids. The Board's Special Study (1) found that the two States, known to the Board to have designed pavements with air voids of less than 2 percent, had the highest wet fatal accident indexes (the ratio of the percent of fatal accidents on wet pavements to the percent of wet time). Based on this information, the Board recommended that FHWA:

> "Promote further research into the relationship of wet-pavement accidents (1) to low void ratios in pavement surface mixes . . . ."

In one ANPRM (11) response, a State encouraged FHWA "to further investigate the feasibility of bituminous pavement design criteria for optimum skid resistance. Principal factors to be considered would be aggregate composition, void content, and asphalt content." Based on the Board's work, it appears that pavements which have been designed for low void ratios in the past need to be monitored carefully.

Surface Treatments.—The Safety Board staff questioned States as to their experience with recycling, rejuvenating, sulfur-extended projects, and fog seals. Of those States that have conducted recycling projects and performed skid tests, one State recorded a "little reduction" in skid resistance and three States reported no changes. Other States indicated that they had used this material on shoulders or had placed a wearing course over the regular mix and had not tested these surfaces. Another State had constructed a sulfur-extended project, but had covered it up with a wearing surface before skid testing.

At one accident location where a rejuvenating agent had been used on the pavement, the Board monitored the State's skid testing. This surface had skid numbers in the 42 to 47 range at 40 mph, with values 3 to 4 numbers lower in the right wheel-tracks.

In an accident investigated by the Safety Board in 1978 (see appendix C, No. 8), the pavement had been treated with a fog seal which was believed to be slippery. Three States indicated that at first a fog seal is slippery, since it initially is a coating of oil that forms a lubricant and reduces the pavement texture. After a short time (a matter of hours if the application rate and weather is appropriate), however, the oil penetrates the mix and is absorbed, and the road surface is supposed to regain friction. Seven States indicated that some fog seals have created slick surfaces, and many States have discontinued use of this and similar surface treatments.

The experience of the 10 States reinforces the need to continuously evaluate the various surface treatments used in order to determine their effect on skid resistance properties. All new procedures developed need to be evaluated throughout their design life. Methods found to be unsafe should be eliminated.

The Safety Board concurs with the intent of FHWA's NPRM (36), which proposes that—

> "Experimental surfaces which may be approved include aggregates or finishing procedures which have not been demonstrated effective by the State highway agency, but which are specifically designed to provide improved skid resistance. These surfaces should only be used in areas of low traffic volumes and low operating speeds for short lengths of roadway. Experimental surfaces shall not be used to correct locations with a high rate of wet weather accidents."

However, there may be a need to evaluate treatments on roads with low traffic volumes and then on roads with higher traffic volumes before they are no longer classified as experimental and are approved for increased use. As materials are depleted and oil products increase in cost, alternative solutions to prolonging pavement life and reutilizing materials will be sought. There is a need to assure that these new methods and procedures are evaluated for skid resistance.

Programs Overview

Local Government Programs.--All States reviewed have a program which allows for resurfacing, surface treating, or grooving wet pavement accident locations on State routes where inadequate skid resistance exists. However, most States do not have a similar program for local or county roads. Many States do not analyze local accident records and conduct skid testing only on request. A couple of States are not allowed by current State laws to test local roads. Other States have tested only a few local locations in the past 5 years. In other States, there is a tendency to increase local testing capabilities and to increase identification of accident locations in local areas. While some local governments are required to use State specifications or "could be aware of approved aggregate sources," other States do not know what specifications the local agencies are using. Highway Safety Program Standard No. 12 states that--

> "Every State, in cooperation with county and local governments, shall have a program of highway design, construction, and maintenance to improve highway safety.

I. The program shall provide as a minimum, that. . .

> E. There is a program for resurfacing or other surface treatment with emphasis on correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces."

Highway Safety Program No. 9 states that--

> "Each State, in cooperation with county and other local governments shall have a program for identifying accident locations and for maintaining surveillance of those locations having high accident rates or losses."

Some States are not complying with the requirements for identification of accident locations and correction of skid resistance problems at the local level. Some States have bought skid trailers using Section 402 funds. In the justifications for the purchase of these trailers, some States indicated that they would also be used to monitor local roads. States should assess whether or not these trailers, obtained with Section 402 funds, are being used as they were intended to be used.

States which are not allowed to test segments off the State highway system should probably seek enabling legislation. State support is essential in this program since most local agencies cannot fully utilize or maintain the necessary sophisticated equipment. However, it must be recognized that States do have budgetary limitations, and some States cannot adequately take care of their own roadways much less all the local roads. Additionally, since most consulting firms do not have the expertise, demand, or capital available to support this machinery, this skid trailer equipment should be maintained and made available to local agencies by the State. States should be available to offer advice and assistance or to provide contractual support in the form of skid testing when requested.

The local and county officials unaware of the State's skid resistance program similarly should be provided with information about the wet pavement accident problem, and the potential for evaluating and improving wet pavement accident locations. These jurisdications also must be informed of the skid resistance capabilities and limitations of the State transportation departments. Liaison between responsible State and local officals must be improved in this program.

Federal-aid Funds and Requirements.--Although all States reviewed indicated that Federal and State standards for mixes were the same, during the investigation of an accident(4), the Safety Board found that one State was using a mix that did not meet Federal standards established by the FHWA division office. In that accident location, the State was using State funds to resurface a road. The mix contained no provision for acid insoluble material. The requirements for a Federal-aid project in that State called for 30 percent insoluble residue in the mix. States should use the same types of proven mixes for similar projects on similar roads regardless of funding used.

Nine of the States indicated that they use both Federal and State funds to improve locations with a high incidence of wet pavement accidents. Similarly all the States indicated that the specifications for pavement designs are the same for State-funded projects as they are for Federal-aid projects. One State added that it uses little Federal-aid for skid resistance projects, partly because of the added "red-tape," but mostly because it has "convinced their resident engineers of the importance of good skid resistance and most projects of this type use State maintenance funds." The one State that did not use Federal funds to improve wet pavement accident locations stated that it has not "improved high hazard locations 6/ where a high number of wet pavements and a low skid number existed because they have not surfaced as a problem."

Nevertheless, analysis of accidents for just wet pavement locations as discussed in the section entitled skid testing (on page 8), not specially identified by the high-hazard program, can highlight marginal pavements.

The NPRM that invites comment on a proposal to replace the current FHWA Federal Highway Program Manual (FHPM) 6.2.4.3 states:

6/ High hazard location lists are printouts that highlight locations with a high number or rate of all types of accidents, and do not specifically highlight locations with just a high percentage of accidents on wet pavements.

"In accordance with paragraph 6 of PPM 21-16, each State is to annually evaluate its highway safety improvement program and provide copies of a summary report to the Federal Highway Administration. The progress and the status of the States' skid accident reduction program on all Federal-aid system highways should be clearly indicated. The division engineer is expected to monitor the States' skid resistance improvement program on a continuing basis, reviewing it for reasonableness and seeing that it is implemented at the earliest possible date."

The NPRM (36) proposes that--

"(c) To insure that the skid resistant properties of a pavement surface are maintained, the FHWA will periodically review the State highway agency's maintenance practices relating to skid resistant pavement surfaces."

In the Safety Board's survey it found that many States report on the progress of their programs annually and that many FHWA division offices are continuously monitoring the State programs. The FHWA had reviewed in-depth the programs of two of the States about 2 years prior to the Safety Board's reviews. In one State the FHWA found the State's program to be acceptable and dynamic. In the other State, in late 1977, the FHWA's division office and State officials had developed a revised skid resistance program. The FHWA division stated that--

"It (the State's skid program) should provide a g d, continuing program to insure that design, construction, and maintenance practices are sound with respect to skid properties and that locations with skid problems are identified.

This program calls for testing of selected locations based on wet-weather accident data. The State had indicated that they planned to run a computer program at least once a year to determine a list of locations with high wet-weather accident rates."

The State developed a list of wet-pavement-accident locations soon after the program was outlined. Officials for the State indicated that the number of locations on this list was too large to manage, and this phase of the program, which involved monitoring accident locations, was not implemented as of the summer of 1979. The officials indicated that management needed to place more emphasis on skid resistance.

This State's implementation of its "skid resistance program" demonstrates the need for an audit of an FHWA-approved program that is audited at least every year for the first few years. In this case, the State and the FHWA had developed what would have been a more comprehensive program. However, there was no followup and the program was not implemented.

FHWA's current NPRM (36) proposes changes in Federal-aid fund participation and the need to review State programs. The Safety Board concurred with the proposed changes and stated:

> "The Safety Board believes that the proposal to have FHWA make evaluations of the States' skid maintenance programs is a positive step. However, the FHWA Federal Highway Program Manual no longer specifies the interval between evaluations and we caution that there will be an initial need for the FHWA to review some States' program activities at least annually.

Currently, the FHPM 6.2.4.3 (Instructional Memorandum 21-2-73) limits corrective treatment of the pavement surface to grooving "or the addition of a thin overlay (less than 1 1/2 inches in thickness) of bituminous material specifically designed to provide the desired skid resistance qualities." The FHPM goes on to say that:

> "Work on pavements of crossing highways and streets that are not a part of a Federal-aid system may be included as a part of the Federal-aid project for a distance not to exceed 50 feet beyond the right-of-way of the Federal-aid highway."

Eight States indicated that at least 2- to 4-inch overlays are needed over any Portland cement concrete surface, and that if there is cracking the greater depths are necessary so that the overlay will hold. On non-Federal-aid highways, two States saw no reason to change the 50-foot restriction. Two States indicated that it was no problem because the FHWA Division either ignored or was not aware of the restriction. Five States believe that the limit of projects should extend for the queue length of stopped vehicles plus the stopping distance where skid problems exist on a non-Federal-aid road which intersects a Federal-aid road.

The Safety Board concurred with and supported the FHWA's NPRM (36) proposal which deleted reference to the 50-foot and the 1 1/2-inch limits (except for Interstates which can use other funds) which now exist in FHPM 6.2.4.3. This change will allow slippery locations on non-Federal-aid roads approaching intersections with Federal-aid routes to be paved for the stopping distance plus the length of traffic queue. Projects where the skid resistance treatment might not have been provided in the past, because a lift of more than 1 1/2 inches is needed, would be funded under the proposed rulemaking.

<u>Miscellaneous</u>

<u>Studded Tires</u>.—To examine this issue States had to be separated as to whether they were southern, central, or northern because there were noticeable differences in attitudes and experiences. In the four southernmost States reviewed, only one State outlawed the use of studs. All .. the southern States indicated that there was such limited use, that they posed no problem.

The central States expressed several viewpoints. Two States believe that studs cause problems. One State's Department of Transportation proposed legislation to ban studs, but the legislation was defeated; the other State restricts the use of studs to 5 months of the year. This second State believes that studs deteriorate Portland cement concrete surface texture and cause rutting of asphalt pavements. The third State also restricts the use of studs to a limited number of months, has observed low usage (3 to 13 percent throughout the State), and believes it has had limited problems.

In the three northern States, one State was able to ban the use of studs during 1978, but currently all three States restrict use to 5 or 6 months. These northern States expressed the following comments:

- o Studs cause highway pavement problems, especially on Portland cement concrete where tining has been done.

- o The effects of studs on skid resistance are not positively known.

- o Studs (1) tend to lower the skid resistance of Portland cement concrete pavements through polishing, but have no significant effect (or perhaps a very slight lowering) on asphalt; (2) may be crushing aggregates; and (3) have a tendency to rut the pavement, which creates pools of water.

- o Studs are "considered to be responsible for substantially increased wear on the pavement surface resulting in rutting. When rutting occurs and water is retained in the ruts, the potential for wet weather accidents increases. The use of studs in the State is declining. The State DOT has supported proposed legislation to ban their use entirely."

During the Safety Board's recent accident investigations, emphasis was placed on examining rutting and determining if the rutting could be related to stud wear. At three accident sites where rutting was observed, the pavements were 5, 16, and 20 years old. None of the rutting could be attributed directly to stud wear, especially on the older roadways where wear would be expected.

As mentioned earlier, no State had determined a correlation between rutting and wet pavement accidents. Nevertheless, research sponsored by FHWA (43, 44) and others (45) has shown that rutting can be caused by studded tires. Consequently, the Safety Board believes additional study is necessary. If a strong relationship between wet pavement accidents and rutting can be proven, the States could use this justification to challenge the use of studs.

<u>Effects of Trucks on New Pavements.</u>--In an ANPRM (11) response, one State stated that "pavement placement and resulting flushing of asphalt is dependent upon the exposure of the new mix to traffic. If the temperature is hot (100°+ F) or if heavy truck traffic occurs within the first 24 hours, flushing can pose a

problem." This comment and two Safety Board investigated accidents have given the Safety Board concern. The two accidents (4) (5) occurred on new pavements where there was a large percentage of heavy trucks and the pavements had begun to flush. During the survey, seven States indicated that they had had no problems with flushing. One State indicated that it tests pavement designs with a geritory machine to examine the possibility of flushing.

Viewpoints expressed by the other three States were--

- There is no fixed minimum time limit between completion of an overlay and opening it to all traffic, including trucks. The necessary time elapsed is a judgment made by the inspector or engineer at the site to prevent damage to the pavement surface. Traffic over new overlays put in place in the summer "benefits" the pavement by reorienting the particles. In the fall, the same procedure may ravel the pavement.

- Trucks and automobiles are not considered separately in deciding when vehicles should be allowed on a newly placed overlay; the temperature of the inplace overlay is the deciding factor. No traffic is allowed on the overlay until its temperature is below 140° F. If traffic is allowed over the pavement when the temperature is higher than 140° F, displacement and deterioration may occur.

- One State indicates success with the following specification with no apparent excess compaction by traffic. "Each layer shall be compacted as specified and allowed to cool to the ambient temperature before the next layer is placed. The contractor shall keep traffic off the asphaltic concrete until it has cooled sufficiently to prevent flushing of the asphalt to the surface, marking or distorting the surface, or breaking down the edges."

Full Width Paving.--A national newsletter (38) has stated

> The problem of upgrading secondary and county roads with limited funds is being solved in several places by the use of asphalt widening strips, later followed by an asphalt overlay over the whole pavement. . . .
>
> The placement of the overlay, can be delayed until warranted by increasing traffic -- which is, of course, the stage construction concept that is an advantage inherent in asphalt use.

While the phase construction process suggested in the newsletter could prevent some accidents by providing wider lanes and clearer roadsides, it could cause a split coefficient of friction. Arizona research (22) and an accident report issued by the Safety Board (5) discuss the accident potential of a split coefficient of friction; a vehicle may have a tendency to rotate if brakes are applied.

Eight States indicated to the Safety Board that roads are usually completely overlayed soon after they are widened. A couple of States added that the widened surface was overlayed immediately for stability or aesthetic reasons. One State indicated that on "3R projects," the road is widened a year before the overlay is put in place. In a couple of States, patching and filling of wheel tracks were observed. This eliminates rutting problems but can create a split coefficient of friction.

Projects that include widening or maintenance practices which improve only one wheel track should be closely monitored to determine the accident history at these locations. If this is a common practice in the State, skid testing should be conducted on both wheel tracks to determine if hazards do exist.

Skid Resistance on Steel and Timber Bridge Decks.—One State has been having problems with steel grid and timber bridges. On one new steel bridge, skid numbers dropped from 74 to 50 in 1 year. Many steel deck bridges have skid numbers in the low 20's. The State added that skid numbers do not increase with the addition of studs.

Previously, the Safety Board has recommended skid testing of timber decking bridges (40). FHWA concluded that these surfaces offer poor resistance against skidding and issued a Technical Advisory (T 5140.5) on October 12, 1978. This advisory concluded that any new bridge with timber decks should have some type of skid resistant surface.

Dissemination of State Studies.—The variability in materials, climate, terrain, and other factors require each State to conduct its own research to determine which mixes and procedures are best for that State. However, some research has developed management tools, processes, accident analyses, and other information which are of potential value to other States, and the research needs to be more effectively disseminated so that all may benefit. Although some States are aware of this research, other States are not and even appear to be duplicating work already done.

Based on the Board's survey, it appears that the distribution of the results of Highway Planning and Research (HPR) projects was limited. As an example, studies relating accidents to wet time (27, 28, 29) were not known to individuals working in this area. In another area, a large study involving several States is being conducted on seasonal variation. The Safety Board found that one State was using its skid trailer and manpower almost entirely on a seasonal variation project. This State, however, was not involved in the coordinated project. If information were disseminated more effectively, duplicated research might be avoided and limited resources would be utilized more effectively.

Most States indicated that there was an adequate transfer in technology through the publications of the Transportation Research Board, AASHTO, and the ASTM. However, one State believed that activities of other States are typically unknown unless Transportation Research Board (TRB) distributes the report. It suggested that perhaps FHWA could produce a document describing other States' activities so that new or unusual procedures and approaches could be considered and evaluated by other States for use in their programs. Another State indicated that it was not aware of some of the research.

The amount of research being conducted by the States varies considerably. While some States dedicate a specific skid trailer for research purposes only, other States conduct limited research based on inventory data and limited additional tests. Appendix D to this report lists some of the published research reports. FHWA should periodically survey States and produce a similar list of references with an abstract of each.

Typically wet pavement research has been concerned with, but not limited to—

- o Texturing of concrete pavements,
- o Skid numbers versus speed,
- o Evaluation of the effects of tread depths, pavement texture, and water film thickness on skid numbers and speed gradients,
- o Wear properties of aggregates,
- o Seasonal variation of skid resistance,
- o Open-graded mixes,
- o Outflow meter evaluation,
- o Experimental mixes,
- o Types of fillers,
- o Correlation of different skid test equipment,
- o Evaluation of grooved pavements,
- o Exposure of vehicles to wet pavements,
- o Manmade materials,
- o Tire-pavement interface and accidents, and
- o Speed zoning

The States reviewed use many methods to train their personnel. The different methods cited included university short courses, special State training sessions, AASHTO and FHWA courses, State laboratory and construction engineering meetings, State dissemination of research findings, and on-the-job training. Most States believed that their training programs were sufficient. One State indicated that it usually held skid resistance and pavement design seminars semi-annually within the State. However, one State indicated in its ANPRM (11) response to FHWA that —

> A detailed instructional text on the various analysis techniques would be helpful and make it easier to instruct technician level of personnel in the use of these techniques. This would be particularly helpful to smaller States with limited staff.

Some of the States indicated that a sufficient number of regional and national meetings have been held and that no other meetings are necessary. In other States attitudes were different. Two States reviewed spoke highly of the FHWA-sponsored regional seminar that allowed "operational type" personnel to exchange ideas on pavement design and skid resistance. In this case, a State with a progressive computer system provided another State with ideas to improve its system. Regional meetings on skid resistance can be especially beneficial where materials and climatology are similar. Other States believe that regional seminars held every 2 years would be beneficial, but cautioned that travel funds are often limited preventing attendance.

A PROPOSED PLAN OF ACTION TO IMPROVE STATE SKID RESISTANCE PROGRAMS

The Safety Board does not believe that all or even a significant portion of wet-pavement accidents are solely the result of inferior pavements. On the other hand, the Board believes that inferior pavements with above-average accident experience are relatively easy to identify and should be a promising area for the reduction of wet-pavement accidents.

Before a rational program can be implemented, some minimum criteria, in the form of skid numbers, must be accepted by agencies. Since skid numbers can vary, a range of skid numbers is probably more feasible. Since projects often must be justified economically, accident records should be used in conjunction with the range of skid numbers.

The use of accident records to identify wet pavement accident locations, as described in HSPS No. 9, appears to be a valid method for pinpointing the wet pavement problem. To provide early notice of wet pavement accident locations, backlogs for inputting data must be reduced, accident locations Statewide must be accurately identified, and analytical capabilities must be expanded. Some of these improvements could be made using HSPS No. 10 (Traffic Records) and HSPS No. 9 funds.

Past criteria (10)(FHPM 6.2.4.3) presented, or referred to, interim recommended values (skid numbers) that had been proposed in a previous study (17) which could have been used with accident data. No where in FHWA's NPRM (36) are minimum skid numbers cited, and it appears that eventually there may be no recommended values. The Safety Board cannot support the complete elimination of skid numbers as a measure of effectiveness.

In the Board's NPRM (36) response, it was stated that--

> The Safety Board offers the following comments to support the establishment of a program for corrective actions based upon skid numbers which we believe can provide sufficient flexibility for the States to accommodate local or regional differences:

1. The works of Moyer, a researcher with Iowa State College in the 1930's, established the need for a coefficient of friction in the range of 0.3 to 0.4 (skid number 30 to 40) to provide adequate skid resistance. (Other reports (17, 20) have recommended frictional values in the same range.) Even ice can provide a coefficient of friction of at least 0.2 (skid number of 20), but at this skid resistance level, any acceleration, deceleration, or sharp steering maneuvers can cause a vehicle to go out of control. Similar responses were involved in a vehicle accident investigated by the Safety Board which occurred on a very slippery (skid number of 8) wet road near Brigham City, Utah, on June 19, 1979. Roadways when wet may be more slippery than ice and yet may have no accident history; however, just as icy roads are sanded to improve their coefficient of friction, evaluation of roads with a low skid resistance level may be warranted regardless of their accident history.

   During the Safety Board's 10-State review, officials from 4 States stated that whenever skid numbers were below 30, they believed that an immediate study should be initiated. A few State officials indicated that, as a minimum, the placement of warning signs was necessary at locations with low skid numbers. One State has a policy to review all locations with skid numbers lower than 25 and another has a policy to review locations with skid numbers less than 35.

Apparently, some States appear receptive to these values. Additionally, three States surveyed by the Board, that initiate corrective action when skid numbers are below 30 and develop a list of locations with wet pavement accident histories for testing, were not among the top 25 States with high wet fatal accident indexes based on the Board's special study (1). This lends further support to the continued use of skid numbers.

The Safety Board continued in the NPRM response (36):

> As a result of its review of State skid resistance programs, the Safety Board believes that the FHWA should establish a program for corrective action based on minimum criteria as follows: First, on roads with a minimum skid number (perhaps of 30 as tested at posted speed limit) where there is an above-average 7/ wet-pavement accident history, signing should be required and a study should be initiated to determine other corrective measures that may be necessary. To make signing more meaningful, a uniform method should be developed to post wet-pavement safe operating speeds. Second, any locations with skid numbers in a range (perhaps of 30 to 40) with an above average wet-pavement accident

7/ Above average should be statistically defined as above the State average using accident data, at a minimum, and weather data. Perhaps different levels of statistical significance can be used for each range based on standard deviations.

history should be examined to determine what improvements or warning might be necessary. Third, any locations with above average wet-pavement accident histories and skid numbers above the established range should be examined for other factors, such as rutting, drainage, or superelevation, that contribute to wet-pavement accidents. Such requirements should provide enough flexibility to be acceptable to most States and yet would be definitive enough to provide improved highway safety. With more program emphasis on testing locations identified as having wet-pavement accident histories, the State skid resistance programs would have more immediate impact. Also, if new pavement designs were required to meet or exceed minimum skid resistance values during their surface life, future demands for pavement overlays or replacement, as well as skid testing frequencies, would be greatly reduced.

After minimum skid numbers and accident frequencies have been adopted by FHWA and the States, FHWA should develop program objectives with goals, objectives, tasks, and evaluation methods for various budgets that can serve as examples to States. After program objectives for various funding levels are developed, the FHWA should initiate rulemaking to require that each State have an FHWA-approved wet weather skid reduction program which is reviewed annually by FHWA. FHWA would audit the programs, not simply accept State certification. For those States with progressive, systematic, and technically sound programs, this rulemaking should have a limited impact; however, for those States placing lesser emphasis on the problem, the rulemaking should provide the impetus needed to obtain an effective program. Annual incentive awards for States which make significant improvements in their programs toward accomplishment of definitive and measurable goals should be used to stimulate activity. A summary of the programs and research conducted by the States, especially Highway Planning and Research Studies, should be compiled and published periodically by FHWA.

In the State's skid resistance programs, priorities must be established for using skid trailers. A complete inventory of skid measurements on all roads would be ideal; however, because of monetary constraints, this system may not be feasible on a priority basis for purposes other than sampling to estimate overall conditions, to isolate a few hazardous locations, and to contribute to sufficiency ratings used for determining priorities for pavement structural improvements. Requirements for a total inventory should be established on a lower priority basis. Innovative procedures should be permitted when developed to fit a particular State's program.

In States with limited funds and wet pavement accident problems, priorities could be set through the analysis of accident locations. This approach would not demand a significant increase in manpower or resources, other than that required temporarily for the development of computer software to define where testing should be conducted. The additional time devoted to analyzing accident locations should be available if the routine inventorying procedure is deemphasized. This approach should result in more productive use of skid trailers and their associated resources. Locations with low skid numbers and above-average numbers of wet pavement accidents thus will be analyzed more often, and improvement of these locations should be much easier to justify. Those locations with low frictional values and no accident histories would be deemphasized. A few States have already adopted this policy.

Overall in the 10 States, emphasis on evaluating wet pavement accident locations is increasing and, as indicated in the data in Table 1, appears to yield high benefits. To improve this method, accurate accident data must be gathered. Based on the Board's discussions with the States, most probably the priorities for skid testing should be:

1) Wet pavement, high accident locations (on and off the State system),
2) Research and evaluation of new surfaces, and
3) General inventory to program funds based on the needs of the system and to highlight a few potential locations in need of improvement.

As a result of its experience in the area of skid resistance, the Safety Board suggests the following plan of action to attack the wet pavement accident problem:

I. The FHWA should immediately establish minimum program requirements which would include:

- o Defined goals, objectives, tasks, evaluation methods, and funding levels. Program objectives similar to those in this report should serve as examples for States to follow.

- o Defined responsibilities of all State bureaus, divisions, branches, and positions involved in the program. This would assure that all offices capable of contributing would have the opportunity to participate in the skid resistance program and would provide feedback. The States should designate a qualified person to have the primary responsibility and sufficient authority for assuring that the program is effectively administered and coordinated with all the principals involved.

- o Emphasis on areas for friction testing to provide for—

  1. Analysis of above-average wet pavement accident locations, including local and county roads.

  2. Research and pavement evaluation, including the testing of new pavements and construction procedures, to assure good quality control of skid resistant properties by testing conducted within the first construction season.

3. General inventories for roadway sufficiency ratings and highlighting potential locations where accidents on wet pavements would be expected.

- After accident locations and new pavements have been evaluated and research has been completed, and as resources permit, monitoring of pavements on primary and secondary routes, through inventories. (Accident statistics tend to indicate that interstate systems need only spot monitoring where certain types of mix designs are used, where geometrics are restrictive, or where volumes of traffic are high.)

- Evaluating aggregate sources and making these results available to local and county agencies. This should be of a high priority in States that have poor or marginal aggregates.

- Evaluations of pavements at the posted speed limit to eliminate the need for gradients.

II. To refine future programs FHWA should:

- Promote programs to define minimum texture requirements.

- Evaluate the various strategies that have been used to fund the calibration centers and fund the strategy which has resulted in the most skid trailers being calibrated annually. Then, require that devices be periodically calibrated.

- Promote an improved exchange of technical data through:

  1. The compilation of instructional information for use by Federal, State, local and county governments.

  2. Periodic regional meetings on skid resistance for the purpose of informational exchange and determining research needs.

  3. Periodically compile a list and description of State skid resistance programs and State research studies for distribution to interested parties.

- Promote further research to examine:

  1. The measurement of rutting and its effects on wet pavement accidents.

  2. The skid resistance properties of new experimental surface treatments.

3. Improved signing systems which would better assist motorists in determining safe speeds on frictionally substandard surfaces.

4. The merits of using a tire in skid testing which is more representative of the range of tread depth on tires used by the driving public.

5. If heavy truck traffic has long-term detrimental effects on skid resistance when allowed on surfaces immediately after constructing or overlaying pavements.

- o Promote full-width surface improvements to eliminate the possibility of developing split coefficients of friction.

- o Increase Federal participation on projects which are now limited by the FHPM 6.2.4.3 when the skid resistance project would require:

  1. A surface treatment more than 50 feet beyond the intersection with the Federal-aid road,

  2. Or an overlay depth greater than 1 1/2 inches when it is in the interest of safety.

- o Promote the acquisition of skid trailers with left- and right-wheel locking capabilities and with the potential to fully examine wet pavement accident locations.

CONCLUSIONS

<u>Findings</u>

1. There is a need for FHWA to review past guidelines and determine what future requirements are needed to assure adoption of comprehensive progressive State skid resistance programs which fully utilize available resources.

2. There is a need for each State to develop a formal wet weather skid reduction program that is approved by FHWA for Federal-aid funding. This program should contain goals and objectives, defined responsibilities, defined emphasis areas, and defined criteria, such as skid numbers and accident frequencies, for action.

3. Although some State skid resistance programs were subjectively judged to be much better than others, some States with limited programs had particular aspects of their programs that were worthy of incorporation into the best programs.

4. In most States reviewed, limited, if any, skid testing has been conducted on local (urban) or county roads, off the State system.

5. Although most States are using accident records to highlight wet pavement accident locations in need of evaluation, other States are not. The use of this data to highlight locations for study appears to have significant benefits and should be emphasized.

6. Most States reviewed have programs that evaluate pavement materials and designs. However, many States do not monitor new pavements initially within the first 2 years following completion to determine if the pavement is slippery.

7. Most States conduct skid tests at 40 mph; in view of the National speed limit of 55 mph, testing should be conducted at the speed limit which is technologically feasible.

8. Full-width surface improvements would reduce the possibility of split coefficients of friction.

9. There are many factors in wet pavement accidents that could distort studies that only relate skid numbers to accident rates; these other factors must be accounted for in skid resistance studies.

10. Calibration of skid trailers is important to assure accurate results, to correlate findings within a given State, and to make the exchange of information between States meaningful.

11. Future skid trailers should have left- and right-wheel locking capabilities, in order to permit testing both wheel tracks at accident locations and to determine if a split coefficient of friction exists.

12. The effect of tread depths of test tires used in skid tests should be evaluated to determine if use of test tires more characteristic of those with little or no tread sometimes used by the driving public will provide more useful data.

13. Complete evaluation of aggregates should be an important phase of a skid resistance program.

14. Pavement surface texture is important in improving skid resistance on road surfaces, and specifications should be adopted for evaluating the acceptability of all new surfaces.

15. Newly developed "experimental" surface treatments must be monitored for skid resistance properties to assure good performance.

16. Improved communication is needed between State, local, and Federal officials to assure that information and research results on skid resistance are available to all.

RECOMMENDATIONS

To assure comprehensive, coordinated skid resistance programs, the Safety Board recommends that the Federal Highway Administration:

— Develop program objectives for comprehensive wet weather skid resistance programs that can be used to both guide and evaluate State programs. (Class III, Longer Term Action) (H-80-52)

— After the program objectives have been developed, require each State to have an FHWA-approved wet weather skid resistance program which is subject to annual audit by FHWA. (Class III, Longer Term Action) (H-80-53)

— Issue a revised Federal-aid Highway Program Manual (FHPM 6.2.4.3) which promotes:

1. Full-width surface treatments.
2. Skid trailers with left and right wheel locking capabilities.
3. Skid testing at the posted speed limit. As proposed in the FHWA NPRM, "Skid Resistance Pavement Surface Design."
4. Evaluation of the skid resistance properties of all newly developing surface treatments.
5. Increase Federal participation on skid resistance projects. (Class III, Longer Term Action) (H-80-54)

— Promote further research to examine—

1. The measurement of rutting and its effects on wet pavement accidents.
2. More effective signing systems to advise motorists of safe speeds on slippery, rutted, or poorly drained wet surfaces and on all new surfaces.
3. Use of tire tread depths more representative of those used by motorists to measure skid resistance.

4. The effect on skid resistance of immediately allowing heavy truck traffic on newly constructed or overlayed surfaces. (Class III, Longer Term Action) (H-80-55)

- Develop a program to enhance dissemination of and the sharing among States of skid resistance information. Elements of the program should include:

  1. The compilation of an instructional text for a state-of-the-art manual for Federal, State, local, and county agencies.
  2. Periodic regional meetings to review skid resistance research and successful operating programs.
  3. Periodic publication of a description of State programs and current research studies on skid resistance. (Class III, Longer Term Action) (H-80-56)

- Evaluate annually the progress of the State skid resistance programs in attaining program goals and publish the findings. (Class III, Longer Term Action) (H-80-57)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ PATRICIA A. GOLDMAN
Member

/s/ G. H. PATRICK BURSLEY
Member

/s/ FRANCIS H. McADAMS
Member

ELWOOD T. DRIVER, Vice Chairman, did not participate.

September 29, 1980

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GLOSSARY OF TERMS

British Portable Tester - A pendulum to which a spring-loaded rubber shoe is attached. The pendulum is allowed to drop and slide over the surface to be tested. Friction is indicated on a dial.

Dolomites - Magnesia rich sedimentary rock that is a carbonate resembling limestone.

Fog Seal - A light application of slow-setting asphalt emulsion diluted with water which is used to renew old asphalt surfaces and seal small cracks and surface voids.

Geometrics - Dimensions and arrangements of the visible features of the highway including pavement width, horizontal and vertical alignment, slopes, channelization, interchanges, and other features the design of which significantly affect highway traffic safety and capacity.

Geritory Machine - A machine used to develop a different type of compactive effort other than the Marshall method--test used to establish proportions of asphalt and mineral aggregates and to define characteristics of the mix.

Locked-Wheel Skid Trailer - Measures the longitudinal friction coefficient developed between the pavement and a tire on a locked wheel that is dragged in the direction of travel of the trailer.

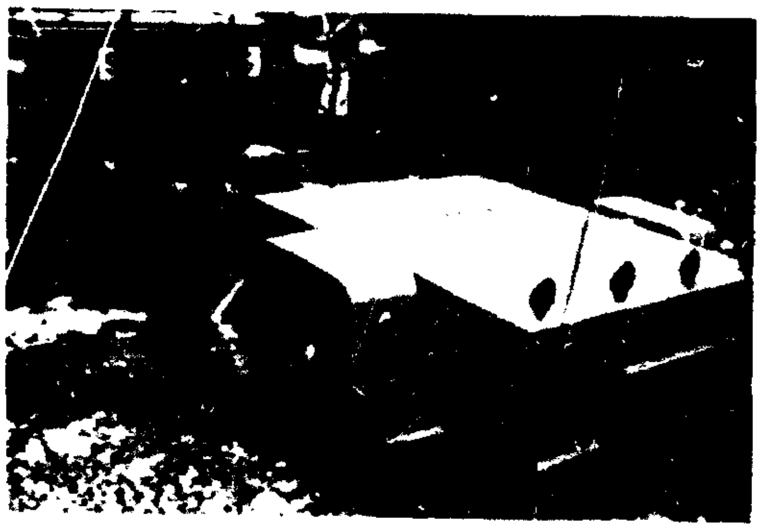
MuMeter Trailer - Measures wet pavement frictional properties developed between the pavement and two rolling pneumatic tires with a 15° yaw angle between the tires.

Open-Graded Mix - A mix using a large percentage of uniform coarse aggregate that allows water to flow through the surface and into water channels between surface aggregates and particles below the surface until it reaches the side of the road. This surface is constructed less than 1 inch thick and is intended to reduce the potential for hydroplaning and spray from other vehicles.

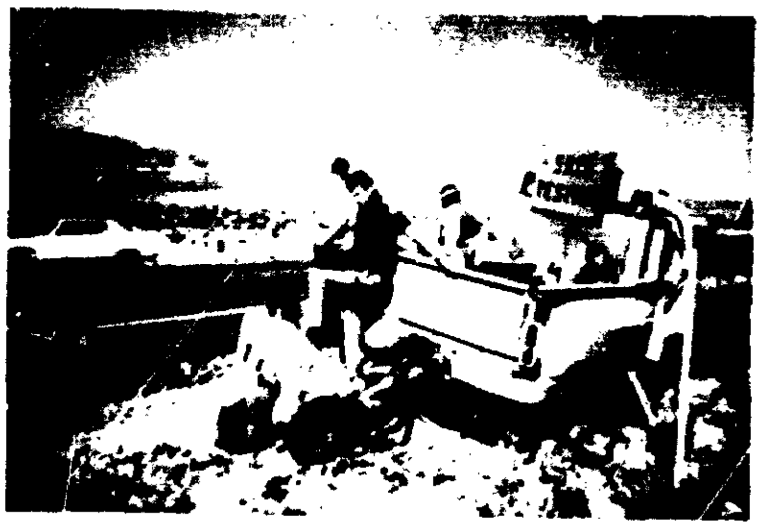
Outflow Meter - A tube with a flange at the bottom. The flange rests on the pavement with a rubber ring interposed between the two. The assembly is weighted down to press the ring against the irregularities of the surface with about the same pressure as exists between tire and pavement. This leaves channels in the surface open, and water in the tube will flow out through them. The time required for the water level to drop a measured distance is taken to be a measure of texture.

Recycling - Repairing old pavement material removed from the surface of the roadway and is usually blended with new material before being put back in place.

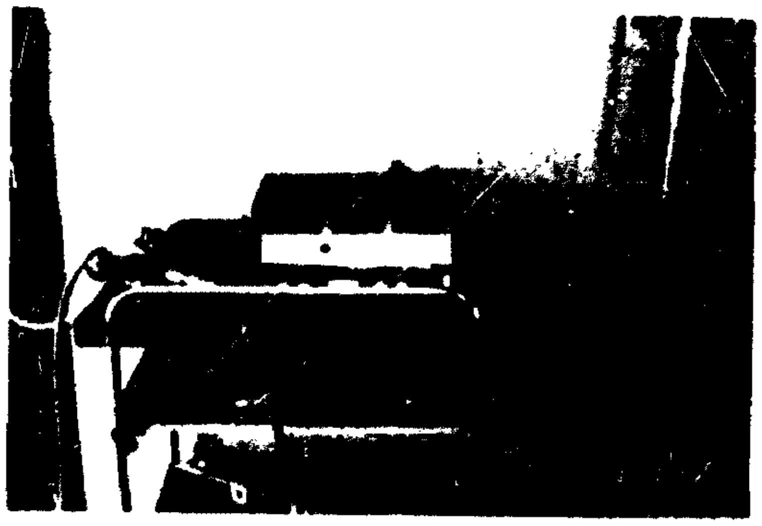
Rejuvenating - The renewal of a road's surface by the addition of a liquid to penetrate and seal an oxidized surface that is structurally acceptable.



Locked-Wheel Skid Trailer



Mu Meter Trailer



Air Bearing Force Plate Equipment
Used to Calibrate Skid Trailers

Outflow Meter Used to
Measure Texture Properties

Rutting - Channelized depressions which may develop in the wheel tracks.

Sand Patch Test - A measured quantity of fine sand that is leveled off above the pavement in various prescribed manners. The area covered will change with the amount of texturing of the surface which can be used to calculate an average texture depth.

Silica - A white crystalline mineral such as sand.

Skid Number - The coefficient of friction times 100 (100x) of a standard tire sliding on wet pavement when tested at 40 mph with a two-wheel skid trailer or equivalent device following the procedures outlined in ASTM E274-79.

Skid Resistance Inventory - An inventory made on a selected sample of surfaces representative of the various combinations of mix designs, aggregates, and construction procedures for pavements which have been exposed to sufficient traffic to allow an appraisal of the skid resistance performance. Additional efforts are often directed toward defining deficient surfaces. Testing is conducted with a skid trailer.

Speed Gradients - The ratio of the change in skid numbers resulting from a change from one speed to another speed. The gradient is used to project the skid number for higher speeds based on testing at lower speeds.

Stability - The ability of a mix to satisfy the demands of traffic without distortion or displacement.

Sufficiency Ratings - All methods used to compare roadways, especially to establish priorities for construction. Such items as roughness, size, and numbers of cracks in the pavement and rutting are measured.

Sulfur Extended - The partial replacement of asphalt with surfur, typically, in the construction of a new pavement.

Tack Coat - A thin layer of asphalt applied to ensure uniform and complete adherence of an overlay.

Tining - Drawing of a series on metal strips (tines) over the surfaces sections of concrete before it cures which produces grooves.

APPENDIX A

HISTORY OF EFFORTS IN THE UNITED STATES TO IMPROVE HIGHWAY SKID RESISTANCE

As early as 1895 the U.S. Department of Agriculture began to conduct traction tests on various types of roads. These tests measured the amount of force required to draw a given load over a particular surface (rolling resistance) to determine the economic impact upon freight transportation. These early friction measuring machines were horse drawn. The force measured was that of a spring in compression which was interconnected to a tractograph. The tractograph consisted of a pencil on a long arm attached to the end of a piston. The pencil point rested on a revolving cylinder which was turned by gears driven by the wagon wheels. Since the cylinder revolved as the wagon moved forward, if a sheet of paper was placed around the cylinder, a continuous record of rolling resistance was obtained. This machine was the forerunner of today's skid resistance measuring devices (12).

In 1924 to 1928, the first reports of field tests in the United States that measured road surface stopping friction were published by the Engineering Experiment Station of Iowa State College. These tests, conducted under the direction of T.R. Agg, measured skid resistance parallel and normal to the line of travel for many different types of road surfaces, dry and wet, using a towed trailer at speeds of 3 to 5 mph, equipped with a spring-type dynamometer-(measuring maximum force). Coefficients of friction of 0.5 to 0.9 (skid number of 50 to 90) were obtained (13).

In 1932 to 1934, problems associated with "higher operating speeds, increased skidding hazards, and the increased number of skidding accidents on slippery pavements" motivated Ralph A. Moyer, Iowa State College, to undertake an extensive program of research that included measurement of skid resistance properties of various types of road surfaces, tests on ice and snow, tests to determine frictional requirements of passenger vehicles at various speeds on horizontal curves, and the friction available in passenger car braking tests. Tests were conducted at speeds of 5 to 40 mph, with an integrating dynamometer capable of measuring average friction forces. Tests indicated that, at speeds in excess of 30 mph, certain wet surfaces were as slippery as packed snow and ice or sleet (14).

The testing equipment and procedures used in these tests set a pattern for measuring skid resistance for the next 20 years. It was concluded by Moyer from this study that:

1. Gritty particles are an important factor in producing a high coefficient of friction - conversely glazing or polishing has an adverse effect on pavements that are wet.

2. To be reasonably free from dangers of skidding, road surfaces when wet should have a straight skid coefficient of 0.4 (SN 40) or higher at 40 mph. (Around 0.3 to 0.4 (SN 30 to 40) is accepted today by many authorities involved in skid resistance research.)

3. A maximum useful coefficient of friction of 0.3 (SN of 30) to counteract centrifugal force was recommended for use in the design of highway curves. (This study is still cited in the 1965 AASHTO guidelines. However, the values 0.11 to 0.16 (SN 11 to 16) that are recommended therein allow simultaneously for longitudinal deceleration . . . a tire can only provide a given amount of friction, as more longitudinal friction is demanded, less lateral friction is available for cornering.

4. The maximum useful superelevation where icy road conditions can be encountered is 0.10 foot per foot. (Today, 0.08 to 0.10 is the maximum used by most States where icy road conditions are likely to exist.)

5. Coefficients of friction of road surfaces decrease with an increase in speed. (Today, it is recognized that the tire-road interface results in the degradation of friction as speed increases.)

In 1938 B. F. Goodrich Company investigated the skid resistance provided by various tread patterns. Emphasis was placed on developing a tread design which provided good drainage for prompt removal of water, optimum wiping of the water from the pavement at the points of tire contact, and continuous contact of the tires with the pavement (15).

During 1938 and 1939, the Oregon State Highway Department examined road surfaces with a towed trailer and corroborated the Iowa findings. An important new development in the Oregon tests was the identification of the high skid resistance provided by the open-textured pavements which had been constructed for this special purpose. The high skid resistance measured on these pavements was attributed to the effective and rapid removal of surface water and what appeared to be a more "intimate" tire-pavement contact than that obtained on the dense-texture pavements. Additional benefits noted included less glare from headlights of oncoming vehicles and better visibility of the centerline marking (16).

In the 1940's and 1950's plant mix seal coats of the open-graded types were introduced in California, Arizona, and Nevada (16).

In 1958, the First International Skid Prevention Conference held at Charlottesville, Virginia, emphasized the definition of problems and identification of research needs. This conference allowed an exchange of information between representatives from various specialized fields, all of whom were working on certain phases of the skidding problem. This conference highlighted the need to correlate test equipment and methods and a need for multidisciplinary accident investigations of skidding accidents. However, the fixing of one minimum coefficient for all roads was termed uneconomical and impossible to achieve (15).

In 1960, the American Society for Testing and Materials (ASTM) Committee E-17 on skid resistance was formed. In 1962, the Tappahannock correlation study of locked wheel skid testing machines was conducted (16). The Highway Safety Act of 1966 renewed emphasis at the Federal level to improve skid resistance. In April 1967, FHWA issued a Circular Memorandum (CM), Pavement Skid Resistance, to field personnel emphasizing the importance of providing good skid resistance on Federal-aid roadways and stressing the need to include provisions for high skid resistance during the design and construction of Federal-aid projects (18).

In June 1967, FHWA's National Highway Safety Bureau issued 13 highway safety program standards. The Standard on Highway Design, Construction, and Maintenance stated:

(1) Every State, in cooperation with county and local governments, shall have a program of highway design, construction and maintenance to improve highway safety.

(2) The program shall provide as a minimum that:

D. There are standards for pavement design and construction with specific provisions for high skid resistance qualities.

E. There is a program for resurfacing or other surface treatment with emphasis on correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces.

During the summers of 1967 and 1968, FHWA conducted a program of pavement skid testing with the cooperation of 17 States using a BPR skid-test trailer. In 1967 the Highway Research Board issued the National Cooperative Highway Research Program Report No. 37 which was the basis for the minimum recommended skid numbers adopted by FHWA in Instruction Memorandum (IM) 21-3-68 and for the Highway Safety Program Manual (HSPM) 12. IM 21-3-68, entitled, "Construction of Pavement Surfacing to Provide Safer Coefficient of Skid Resistance," pointed out the benefits of good skid resistance and encouraged improvement projects. More importantly, the IM informed the States that in the interests of safety, Federal funding would be available for work to resurface pavements with skid numbers of less than 35.

In May 1968, FHWA issued a followup advisory CM, entitled "Plant Mix Seal Coats," to better describe plant mix seal coats and encourage States to use them to provide high skid resistance on existing pavements (18).

FHWA's 1969 Highway Safety Improvement Program, as outlined originally in Policy and Procedure Memorandum (PPM) 21-16, and revised on May 3, 1972, was superseded by the Federal-Aid Program Manual (FHPM) 6.8.2.1 on July 3, 1974, and later revised on November 18, 1976. It called for a program of projects to detect and correct hazardous or potentially hazardous locations, elements or sections of the Federal-aid highway system. Accident data was to be used to identify hazardous spot locations. Continuing systematic corrections and evaluations were required for skid-prone locations.

APPENDIX A

In March 1971 FHWA issued Volume 12 of the Highway Safety Program Manual. The manual called for a program under which any pavement that could not meet the "recommended minimum interim skid numbers" would be analyzed for corrective action. Specific consideration was to be given to skid resistance qualities in the materials, design, and construction of new pavements.

In May 1971 the Subcommittee on Investigations and Oversight of the House Public Works Committee conducted hearings on skid resistance. The Subcommittee urged FHWA to provide leadership to the States and to encourage better State response on testing, reporting, and improving skid resistance. The Subcommittee indicated that the hearings did not terminate its concern and that future hearings were anticipated. In the fall 1972 the Central Field Test Center at Texas Transportation Institute was opened for a pilot program to calibrate, correlate, and evaluate skid trailers. In 1973 it began full time operations.

On July 1973, FHWA issued IM 21-2-73 (now FHPM 6.2.4.3) which required the States to examine current pavement design, construction, and maintenance practices for systematic identification and corrections of wet pavement accident locations. The program also called for complete State skid measurement data, and appraisals of present data, engineering evaluations of skid, geometric, traffic, weather and other factors for corrective action, a statement concerning Federal-aid fund eligibility, design, request for progress reports, and guidelines on technical details of evaluation, design, and construction for skid resistance surfaces.

In 1977 the Second International Skid Prevention Conference was held to facilitate an international exchange of information on all aspects of wet weather skidding accidents on highways. Primary emphasis was placed on research results and their application, developments in vehicle design, and operating agency practices and programs known to have a significant influence on reducing wet-weather accidents. The interaction among the driver, the vehicle, and the pavement surface was of prime concern.

In November 1977, FHWA issued an Advanced Notice of Proposed Rulemaking which solicited comments on:

1. Skid inventory requirements,
2. Methods for skid measurements,
3. Need for skid test calibration centers,
4. Skid resistance criteria for the design of pavement surfaces,
5. Programs to reduce skidding accidents on existing highways, and
6. Relationship of pavement characteristics to skid resistance.

In October 1978, direct Federal funding for the complete operation of the skid resistance field test centers was halted. Interim support was provided until the spring 1980 when a Federal contract for a central calibration center to continue providing services was signed.

APPENDIX A

In April 1980, FHWA issued a Notice of Proposed Rulemaking which proposes "to establish policy, guidelines, and related criteria for the design and use of skid resistant pavement surfaces on roadways. The use of experimental surfaces, the methods of determining skid resistant characteristics, and the categories of Federal-aid funding are included."

APPENDIX B

NTSB QUESTIONNAIRE ON STATE SKID RESISTANCE PROGRAMS

What is the Organizational Structure and Involvement in Skid Resistance?

WET WEATHER SKID REDUCTION PROGRAM (WWSRP)

1. Does the State have a WWSRP?

2. What are the long-range and short-range goals of the WWSRP?

3. What is the time schedule for these goals?

4. What is the procedure for performing and attaining these goals?

5. How is attainment of the goal to be evaluated?

6. What is the staff size of the WWSRP? $ ___
   What % of research is that? Operations, materials $ ___
   What % of DOT? $ ___

7. Number of trailers owned, operated and maintained by the State?

8. How many tests and what types of tests are performed annually?

9. What percent of the State systems has been inventoried?

10. What is the total mileage of the State system?

11. What are the capabilities of the accident record?
    i.e., 1/10, 1/100 mi., scanning. What is the backlog in entering accidents? Can accident records be correlated to pavement type, geometrics, and skid number?

SKID MEASUREMENT

1. Are periodic skid tests being conducted?

2. Are skid numbers and gradients obtained on a selected sample of surfaces representative of the various combinations of mix designs, aggregates, and construction procedures for pavement which has been exposed to sufficient traffic to allow an appraisal of the skid resistance performance? Is this information used to estimate the condition of pavement for similar conditions of surfacing and traffic and to determine critical locations?

3. Are skid numbers measured at the posted speed limit, operating speed, or 40 mph?

4. Are records of the coefficient of skid resistance for new pavement surfaces and periodic additional skid tests conducted and made available to roadway designers for assistance in determining which design mixes and construction procedures produce desirable skid resistance qualities?

5. What type of special studies have been or are now being conducted to relate skid resistance and design properties?

6. How are sites selected for periodic skid testing?

7. Are skid numbers related to accident rates?

8. What is the percent of wet pavement accidents in the States? What percent of the time is pavement wet in the State? How is this determined?

9. Is weather data used? Would it be used if it was readily available?

10. Are complete inventories useful or beneficial?
Should only complaint- or high-hazard locations be looked at?

11. How do you believe the calibration centers should be utilized? Funded? Restructured? How often do you recalibrate? Have you recalibrated since October 1, 1978?

12. What wheel track is examined?

13. Where a high-hazard location has a high percentage of wet pavement accidents is pavement texture or drainage examined?

14. What is the State's philosophy toward using a tire with less tread depth?

PAVEMENT DESIGN AND CONSTRUCTION

1. Are standards for skid resistance being incorporated in the design and construction of all new pavements in the State and local highway system?

2. Is an evaluation of current pavement design, construction, and maintenance practices being made to insure that skid resistant properties are suitable for the needs of traffic?

3. Are pavement surfaces being designed on the basis of the properties measured at the expected operating speeds?

4. Are designs of surfaces which do not provide satisfactory skid numbers with corresponding low speed gradients at the completion of construction reviewed and necessary modifications made for future work?

5. Are mixes designed so that losses in skid resistance during the design life are at a minimum? (recommended 15 SN's)

6. Are good skid resistance aggregate (hard, sharp particles) readily available that produce a durable skid resistant surface?

7. If good aggregates are not available, are special aggregates imported, even though considerably more expensive than locally available natural materials? Perhaps for critical highway locations?

8. Are specific aggregate types and sizes which experience has shown will reduce skid resistance qualities excluded from the wearing surfaces? Are quarries rated or closed for this purpose?

9. Are open graded plant mix surface coarses used in the State? What has the State experienced with this type of mix?

10. Are large size aggregate (3/4 in. or larger) or surface treatments (chip seal) used in the State? What has the State experienced with this type of mix?

11. What transverse texturing procedures are used in the State?

12. How much longitudinal grooving has been completed in the State?

13. What type of typical tests are run on aggregates in the lab? L.A. Wear, Acid Insoluble, British Polish Stone Valve, Fractured Face Count, Petrographic Analysis.

14. The properties required for good skid resistance at the surface may be distinct from, and in the case of high voids, may be directly opposed to those desired in the structural mat. Are specific designs and specifications for surface coarses independent of the structural requirements of the mat used on the surface?

15. What type of training is available for persons involved in pavement design and skid resistance?

16. What type of finishing is specified on PCC?

PAVEMENT TREATMENT FOR SKID RESISTANCE

1. Is there a program at the State and local levels for resurfacing or surface treating streets or highway locations where inadequate skid resistance contributes to high accident experience?

2. Are Federal-aid funds used to improve segments of roadways that have a high wet weather accident experience? If Federal funds are used, are there special considerations on mixes imposed by the FHWA division engineer? Are the Federel requirements waived if State funds are used exclusively?

3. Is there a systematic plan for checking skid resistance at problem locations? i.e., high accident experience, indications of excessive skidding, potentially hazardous locations such as sharp curves and intersection approaches on high speed highways, locations where traffic is heavy, locations where the pavement is constructed of materials known to polish rapidly, locations where the pavement is in poor condition.

4. How is a location determined to be in need of an engineering evaluation for corrective action - by a high frequency of wet weather accidents, by a low skid number, or by a combination of the two?

5. Does the State have a traffic records system which correlates accident experience with highway data?

6. Have the State and local agencies established and implemented a systematic program for corrective resurfacing of a roadway which includes:

   a. Methods for immediate, although possibly temporary, spot improvement surface treatments on roadway sections with inadequate skid resistant characteristics?

   b. A system for assigning priorities for temporary or permanent resurfacing or other corrective measures for roadway segments with high or potentially high skid-related crash experience?

   c. A systematic correction program for entire roadway routes having inadequate skid resistant surfaces?

7. Does the State have minimum acceptable coefficients of skid resistance (criteria) which require action to be taken to evaluate deficiencies, to correct deficiencies, etc?

MISCELLANEOUS

1. Are studs allowed in the State on snow tires? What effect have they had on the pavement related to the coefficients of skid resistance?

2. How soon after overlays are completed are trucks allowed? Does this effect compaction?

3. Are thicker treatments (greater than 1 1/2 inches) needed, specifically over concrete?

4. Should the 50-foot concept on intersecting non-Federal-aid roads be extended to allow for stopping distance plus queue? Do you have examples for this?

5. What has been the effect of the FHWA Division, Region or Headquarters on the State's program?

APPENDIX B

6. What changes does the State feel are needed?

7. Have recycling projects been conducted in the State? Is this used as a wearing surface? What has been the skid resistance experience?

8. When upgrading secondary roads by widening, are complete overlays placed immediately or are overlays delayed until warranted by increasing traffic?

9. Are fog seals or similar processes used on State roads to rejuvenate pavement? Have these ever been skid tested?

10. In a dense graded asphalt mix, what is the design range for void ratios?

11. Does the State skid test for local jurisdictions if requested?

APPENDIX C

SKIDDING ACCIDENTS INVESTIGATED BY THE SAFETY BOARD

In the last 10 years, the Safety Board has investigated the following accidents which occurred on wet pavements:

1. About 1:55 p.m., July 15, 1970, a chartered tour bus carrying 53 school age children and their counselors on a sight-seeing trip into Pennsylvania was westbound on U.S. 22 (I-78) during a rainstorm. While traveling about 55 miles per hour on a slight curve to the right, the bus traversed a section of highway where excessive water was flowing across the highway, "hydroplaning" ensued and the driver lost control of the vehicle. The bus skidded and rotated 180° clockwise and into a cable-type guardrail, which failed to hold the bus, permitting it to roll (or vault) onto a steep embankment with a 30-foot drop. Eighteen occupants were ejected, resulting in death to 7 students and varying injuries to 47 other occupants.

   The National Transportation Safety Board determined that the probable cause of this accident was either dynamic or viscous hydroplaning of the front wheels of the bus followed by a skid from which the driver could not recover. Contributing factors included low basic skid resistance of the pavement in wet weather, and the probable presence of backed up water on the pavement.

Rain Intensity: Light rain preceded by a heavy shower.
Skid No. Range (40): 23 to 47
Other Comments: Water backed up at drains in the median due to debris and matted vegetation.
Tires: Left side, rear inside, and outside were smooth, all other acceptable.
Report No.: NTSB-HAR-71-8.

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2. At 6 p.m. on June 6, 1976, an empty southbound tractor-semitrailer (truck) collided with a northbound intercity-type bus near Hamilton, Georgia, on U.S. 27. The bus was the second vehicle of a four-vehicle convoy. Two southbound automobiles were stopped while the first waited for the convoy to pass before turning left into a driveway. The truck was following the automobiles; when the truckdriver braked in an attempt to avoid the cars, his truck jackknifed and collided with the bus. The vehicles collided on a two-lane highway in a sparsely populated, rural area; a light-to-moderate rainshower was in progress. The truckdriver and busdriver were killed in the collision and 19 of the 20 bus passengers were injured.

   The National Transportation Safety Board determined that the probable cause of this accident was the failure of the truckdriver to operate at a proper speed and with a proper level of attention to and concern for safe driving.

Skid No.: 40
Other Comments: The truck may have jackknifed due to driver action such as downshifting, brake application, and/or steering.
Estimated Speeds: 50-55 mph.
Reported No.: NTSB-HAR-76-5.

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3. On October 11, 1975, about 9:05 a.m., a charter bus owned and operated by the Metropolitan Coach Corporation was eastbound, in heavy rain, on Interstate 495 in Bethesda, Maryland. As the bus negotiated a curve to the right at 50 mph, the rear wheels of the bus lost traction and the rear of the bus began to slide from side to side. In its final slide to the right, the bus rotated counterclockwise 160° and contacted the guardrail. The bus rolled over, rotated 270° about its longitudinal axis, and landed on its left side in a roadside ravine. Of the 29 bus occupants, 26 were injured.

The National Transportation Safety Board determined that the probable cause of this accident was the inadequate frictional coefficient between the tires and the pavement; the frictional coefficient could not resist the centrifugal force of the bus as it traversed the curve at the posted speed limit.

Skid No. (40): 36
Other Comments: Recommendations were issued calling for increased superelevation of the curve and for NHTSA to compare frictional coefficients obtained with a commercial vehicle tire to that obtained with an ASTM E-274.
Report No.: NTSB-HAR-76-6.

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4. About 1 a.m. on December 4, 1975, a 1975 Peterbilt tank truck towing a 1970 Peerless full trailer (tank), owned by Union Oil Company of California, went out of control on the Alaskan Way Viaduct in Seattle, Washington, as the driver attempted to negotiate a curve on the traffic-polished concrete roadway at 52 mph and during a rainstorm; the posted speed limit was 50 mph. The trailer jackknifed and struck a viaduct support column. The trailer's tank ruptured and its cargo of gasoline spilled. Fire ensued, spread along the viaduct, and spilled to the ground below, where it ignited 4 railroad freight cars, 30 motor vehicles, and adjacent buildings. The accident caused property damage estimated at $750,000. Two firemen were injured while fighting the fire.

The National Transportation Safety Board determined that the probable cause of this accident was the failure of the driver to reduce the speed of the combination vehicle to permit safe negotiation of the curve under existing road and weather conditions. Contributing to the loss of vehicle control was the marginal traction capability of the pavement for the posted speed limit.

Skid No. Range (40): 26–46
Other Comments: Mix of lock and antilock brakes. Concern for the relationship of commercial tires to ASTM E-274 testing tire.
Report No.: NTSB-HAR-76-7.

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5. About 4:20 p.m., on July 14, 1977, a 1972 Ford sedan southbound on U.S. Route 69 about 19.4 miles south of McAlester, Oklahoma, went out of control on wet pavement, rotated counterclockwise while skidding into the opposing traffic lane, and collided with a northbound Midas Mini Motor Home. All six persons in the sedan were killed; the driver and right front passenger in the motor home were killed and the six other passengers of the motor home were injured.

The National Transportation Safety Board determined that the probable cause of this accident was a combination of the low skid resistance of the wet road surface and the lax maintenance practices of the owner of the Ford sedan which had an unsafe tire and an unbalanced brake system. A factor contributing to the accident was the driver's unfamiliarity with the mechanical conditon of the Ford sedan.

Rain Intensity: 0.24 to 0.54 inches in 18 minutes (moderate to heavy).
Skid No. Range (40): 11.6 - 29.9, with accident vehicle tires 11.6 and 26.5
Texture Depth: 0.004 inches Outflow Meter: 11 to 609 secs.
Age of Pavement: About 3 months
Comments: Visible flushing, no special provision for acid insoluble residue in the specifications, left rear tire worn, right rear brake rusted, some contributing human input - braking, steering, or accelerating.
Report No.: NTSB-HAR-78-2.

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6. At 4:15 p.m., on August 26, 1977, a 1973 Dodge van and a 1977 Peterbilt truck, pulling an empty 1977 Reliance full trailer, collided head-on during a moderate-to-heavy rainstorm on U.S. 91, 8 miles north of Scipio, Utah. The eight occupants of the van were killed and the truckdriver was injured.

The National Transportation Safety Board determined that the probable cause of this accident was either or both drivers failed to maintain their vehicle in the proper traffic lane for reasons that could not be determined.

Rain Intensity: 0.1 to 0.5 inches per hour (moderate to heavy).
Skid No. Range (40): 23-40 (3 months later)
Age of Pavement: 52 days
Comments: Testing revealed split coefficient of friction, lack of crown, appearance of flushing, a dense mix with low voids, malfunction of the anti-lock system created the potential for wheel lockup.
Report No.: NTSB-HAR-79-1.

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7. At 8:07 p.m., on Sunday, September 25, 1977, an empty tractor-semitrailer was traveling eastbound on I-70 in downtown St. Louis, Missouri, when the truckdriver lost control of his vehicle on wet concrete pavement in trying to avoid another vehicles. The tractor struck, broke, and overrode a concrete median barrier, vaulted into the westbound lanes, and collided with a westbound automobile. All three occupants in the automobile died; the truckdriver was injured slightly.

The National Transportation Safety Board determined that the probable cause of this accident was the loss of tractor-semitrailer control during evasive maneuvers made by the truckdriver in response to improper lane changes by an eastbound automobile driver.

Rain Intensity: Light rain, but rain had been heavy 10 to 15 minutes before and water was running downgrade.
Skid No. (40): 0.25 to 0.30 (2 years before)
Age of Pavement: about 20 years
Comments: ruts 1/16 to 3/16 inch deep, 60 percent of the accidents were on wet pavement, truck was reported to be traveling above the 55 mph speed limit in a weave area when another car pulled up in front of him. The truckdriver began an evasive maneuver and lost control of his vehicle.
Report No.: NTSB-HAR-79-3.

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8. On November 5, 1978, at 8:46 a.m., an eastbond 1974 Ford pickup truck crossed the median and collided nearly head-on with a westbound 1973 Chevrolet Monte Carlo, which was towing a Chevrolet Vega, on the Kansas Turnpike (I-70) at milepost 208 near Lawrence, Kansas. The truckdriver and five persons in the automobile died as a result of the collision or the fire which ensued. A sixth occupant of the automobile was injured. An eastbound witness, who had been traveling in the outside lane, told investigators that he saw the immediate precrash events and that when he tried to stop his vehicle by applying his brakes, his vehicle immediately rotated 180° clockwise and skidded rearward off the right edge of the pavement.

Rain Intensity: The pavement was wet.
Age of Pavement: Fog seal 4 to 5 months earlier

Texture: 0.0036 inches
Comments: The following testimony of the witness tended to indicate that this accident was human factor related. However, in addition to the smooth surface, a negative superelevation was identified.

* * * * *

9. About 3:40 p.m., p.s.t., November 11, 1978, a stationwagon with 13 occupants exited from Interstate 10 (San Bernardino Freeway) onto a branch connection ramp which led to the southbound California State Route 7 (Long Beach Freeway). It was raining and the roadway was wet. As the stationwagon negotiated the ramp, the driver lost control of the vehicle and it crashed through the bridgerail and fell to the roadway below landing on its roof. The driver and six passengers were killed and the other six passengers were injured.

The National Transportation Safety Board determined that the probable cause of this accident was the driver's loss of control of the stationwagon on the branch connection ramp, which resulted from (1) the road surface's low coefficient of friction, (2) the speed of the vehicle, (3) the degraded condition of the vehicle, and (4) the intoxication of the driver.

Rain Intensity: 0.11 to 0.30 inches per hour
Skid No. Range (25) - 28-29
Comments: 52 percent of the accidents were on wet pavement, no rear brakes, two adjacent tread grooves on each rear tire were less than 1/32 inch in depth, 0.18 BAL.

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10. On June 19, 1979, at about 1:40 p.m., m.d.t., a Pacific Trailways bus, southbound on I-15 just north of Brigham City, Utah, encountered a brief thundershower and skidded out of control. The bus was traveling in the southbound median lane. The bus rotated, crossed the outside lane and shoulder. It went through the guardrail backwards, and continued down a 15-foot embankment. As the bus was going down the embankment, it rolled partially onto its top and came to rest on its side about 60 feet from the edge of the outside driving lane. One passenger was killed and 11 others were injured to various degrees.

Rain Intensity: Heavy rain as the bus approached the accident site
Mu Number Range: 10-46 probably 10 where the bus lost control (test at 50 mph)
Equivalent Skid No. 50: 8-33
Texture Depth: 0.002 inches
Comments: Witnesses estimated speed at 58-60 mph. Rear tire tread depths 4/32 to 14/32. A segment of road appeared to be bleeding, and rutting of up to 3/8 inch deep was measured.

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11. About 7:40 a.m., c.d.t., on Monday morning, July 30, 1979, two vehicles, a passenger van and a tractor-semitrailer, collided on two-lane U.S. Highway 30 near Hinckley, DeKalb County, Illinois, which has a 55 mph speed limit. It was raining heavily and the pavement was wet. The van was traveling east and approaching a eastbound stalled automobile which was stopped with its left wheels resting on the white line that delineated the pavement edge. The tractor-semitrailer was traveling west. As the two opposing vehicles came nearer each other, the van crossed the centerline into the westbound lane and struck the truck head-on.

Six of the van occupants were killed and the remaining seven were severely injured. The truckdriver was not injured; he had no passengers.

Rain Intensity: 3 inches in 1 1/2 to 2 hours
Skid No. Range (40): 39 to 50
Comments: Visible rutting with mean values of 0.20 to 0.34 inches with a maximum of 0.53 inch rut depth. Left front van tire inside tread depth 1/32 inch. Driver age - 16 years. The vehicle could have hydroplaned if steered into the water channel at speeds of 41.6 to 53.5 mph.

* * * * *

12. About 6:31 c.d.t., on October 22, 1979, vehicle 1, a 1965 Comet, was traveling from the north side of Columbus, Indiana, to the southside. It stopped at the traffic signal at the intersection of S.R. 46 and U.S. 31A, then continued south on U.S. 31A. Driver No. 1 stated that the rear end of his car began to slide to the right about 600 feet south of the intersection and continued to rotate as it crossed into the northbound lanes. When the vehicle was about 90° to the centerline of the road and in the northbound lane, it was struck in the right side of the vehicle by vehicle 2. Total travel from the point where the driver stated he lost control to impact was about 500 feet.

Vehicle 2 was traveling to Columbus, northbound on U.S. 31A. As vehicle 1 crossed into the northbound lane, driver No. 2 braked but struck head-on into the right side of vehicle 1. Impact was about 1,100 feet south of intersection with State Route 46.

The passenger in vehicle 1 was killed. The remaining five occupants received minor injuries.

Rain Intensity: 0.25 to 0.43 inches per hour recorded in Indianapolis.
Skid No. Range (40): 22 to 36
Texture Depth: 0.002 to 0.007
Comments: Vehicle 1 - tread depth right front 0 - 1/32 inch, left front 1-3/32 inch, driver 1 - licensed 2 weeks, owned vehicle for 5 days. Speed limit 45 mph.

APPENDIX D

RESEARCH PROJECTS ON SKID RESISTANCE

<u>**Texas**</u>

- Report No. 45-4. Pavement Surface Texture as Related to Skid Resistance. August 1967. (Hankins)
- Report No. 45-5F. Pavement Material Properties as Related to Skid Resistance. August 1969. (Hankins)
- Report No. 126-1. Field Friction Performance of Several Experimental Test Sections. March 1971. (Underwood)
- Report No. 126-2. Aggregate Polishing Characteristics: The British Wheel Test and the Insoluble Residue Test. January 1971. (Underwood, Hankins, Garana)
- Report No. 126-3F. Pavement Surface Polishing Characteristics: A Circular Track Test. June 1974. (Hankins, Underwood, Darnaby, Ledbetter)
- Report No. 133-1. Relationship of the Tire-Pavement Interface to Traffic Accidents Occurring Under Wet Conditions. June 1969. (Dean)
- Report No. 133-3F. The Degree of Influence of Certain Factors Pertaining to the Vehicle and the Pavement on Traffic Accidents Under Wet Conditions. September 1970. (Hankins, Morgan, Ashkar, Tutt)
- Report No. 135-2. Factors Affecting Vehicle Skids: A Basis for Wet Weather Speed Zoning. February 1973. (Weaver, Hankins, Ivey)
- Report No. 135-4. The Use of Rainfall Characteristics in Developing Methods for Reducing Wet Weather Accidents in Texas. July 1975. (Hankins)
- Report No. 138-1. Microtexture Measurements of Pavement Surfaces. February 1970. (Galloway and Tomita)
- Report No. 138-2. Macro-Texture, Friction, Cross Slope and Wheel Track Depression Measurements on 41 Typical Highway Pavements. June 1970. (Galloway and Rose)
- Report No. 138-3. Highway Friction Measurements with Mu-meter and Locked Wheel Trailer. June 1970. (Galloway and Rose)
- Report No. 138-4. Effects of Pavement Surface Characteristics and Textures on Skid Resistance. March 1971. (Galloway, Epps, Tomito)

- o Report No. 147-3F, "Automobile Tire Hydroplaning - A Study of Wheel Spin - Down and Other Variables," (Stocker, Dotson, Ivey) August 1974.
- o Summary Report No. 138-5(S). The Effects of Rainfall Intensity, Pavement Cross Slope, Surface Texture, and Drainage Length on Pavement Water Depths. May 1971. (Galloway, Schiller, Rose)
- o Summary Report No. 138-6(S). Influence of Water Depths on Friction Properties of Various Pavement Types. August 1974. (Galloway, Scott, Rose, Schiller)
- o Summary Report No. 138-7F(S). Vehicle—Pavement Interaction Study. August 1975. (Olson, Johnson, Galloway)

<u>California</u>

- o Evaluation of Minor Improvements--Grooved Pavements - December 1972. (Karr)
- o Evaluation of Minor Improvements--Grooved Pavements (Supplemental Report) - September 1975. (Smith, Elliot)
- o Surface Textures for PCC Pavements - April 1978. (Neal, Peck, Woodstrom, Spellman)
- o Copperopolis Test Section Binder Modifiers as Construction Seals - December 1974. (Predoehl, Nelson, Kemp)
- o A Method to Determine the Exposure of Vehicles to Wet Pavements - January 1972. (Karr)
- o California Skid Resistance Studies, Final Report - February 1974. (Apostolos, Doty, Page, Sherman)
- o Reduction of Accidents by Pavement Grooving - August 1968. (Beaton, Zube, Skog)
- o Minor Research Project titled "Compare Pavement Polishing of Right and Left Wheel Tracks." Memorandum dated January 30, 1978.

<u>Missouri</u>

- o MCHRP72-2 "Correlation of a Portable Skid Tester with the Missouri Skid Trailer."
- o MCHRP73-3 "An Investigation of Skid Resistance in Missouri."
- o MCHRP74-4 "An Investigation of Skid Resistant Asphaltic Mix Designs."

- MCHRP74-5 "An Investigation of the Durability of Skid Resistance of Wire Combed PCC Pavement Surfaces."

<u>Virginia</u>

- An Investigation of the Slipperiness Characteristics of Highway Pavements Including Painted Areas, Bridges, Grades, Curves, Intersections, and Lateral Cross Sections, (Mahone), 1962.

<u>Florida</u>

- Report 198-A, Skid Resistance Evaluation—Wearing Course 4, May 1977, (Potts)

<u>Pennsylvania</u>

- Pub. No. 33 - Tentative List of Commercial Producers of Coarse Aggregates, April 1978.

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